(NASA-CR-166701) THE 50 AMP-HOUR NICKEL CADMIUM BATTERY MANUAL (McDonnell-Douglas Corp.) 82 p HC A05/MF A01 CSCL 10C

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THE NASA STANDARD 50 AMP-HOUR NICKEL-CADMIUM BATTERY MANUAL

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50 AMP-HOUR NICKEL-CADMIUM BATTERY MANUAL

PROJECT MODULAR POWER SUBSYSTEMS

SUBMITTED UNDER NAS 5-23844

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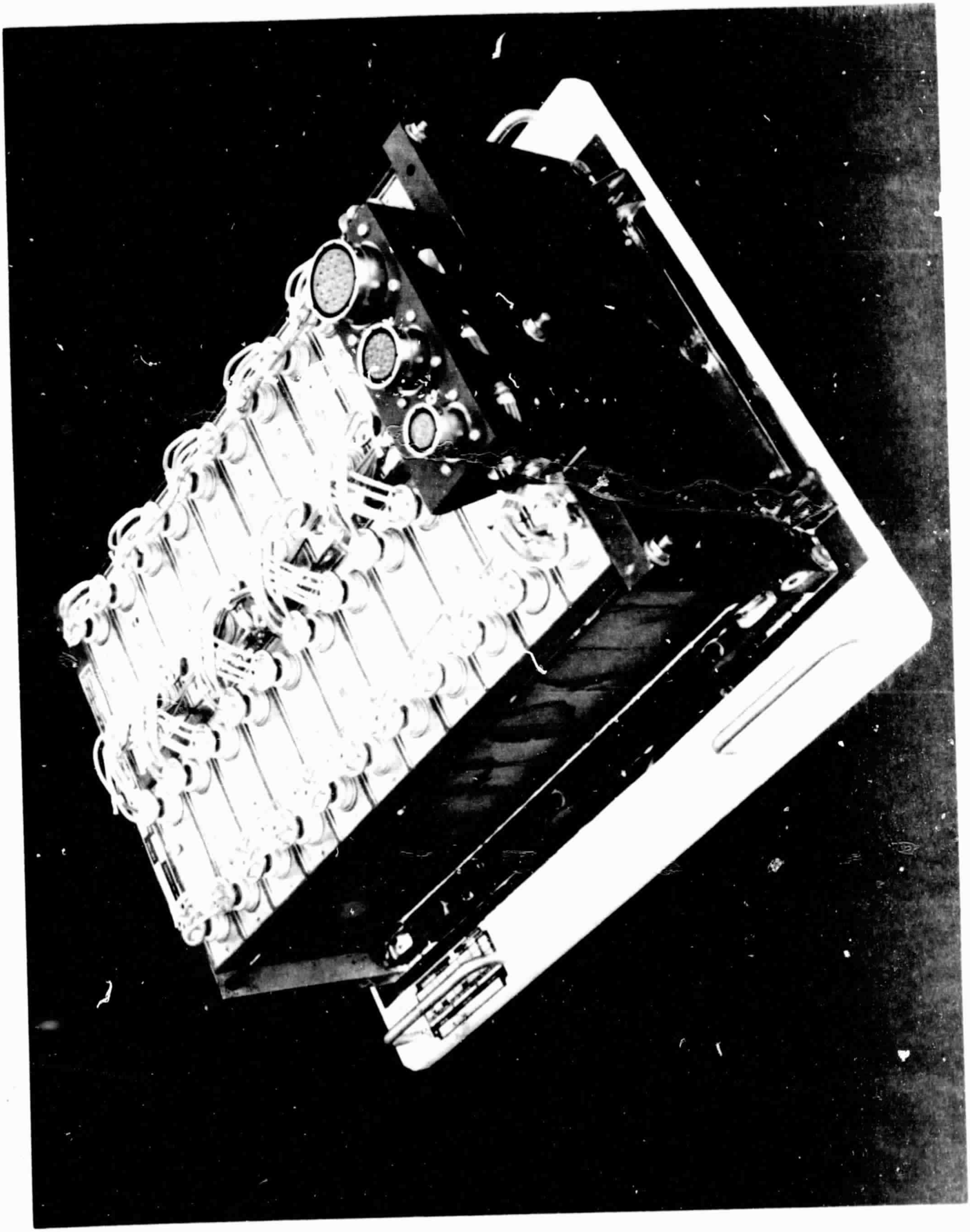


1.0 INTRODUCTION

The battery pictured on the preceeding page, is the 70A237005-1007 Nickel-Cadmium battery which was developed by McDonnell Douglas Astronautics Company - St. Louis for NASA Goddard. The battery accommodates twenty-two cells. The cells are 50 A.H. Nickel-Cadmium hermetically sealed cells which are fabricated and tested in accordance with a comprehensive NASA Goddard approved cell manufacturing control document. The battery is designed with a minimum battery to cell weight ratio consistent with adequate containment for operating conditions and dynamic environments and minimized weight. The battery is fully qualified and the environments to which it has been successfully subjected were selected by NASA Goddard to cover a wide range of probable uses.

The battery is suitable for either near-earth geosynchronous missions, is compatible with passive or active thermal control systems and may be electrically controlled by a variety of charging routines.

The initial application of the 50 A.H. Batteries is a near-earth mission aboard the Landsat D Satellite.

2.0 CELL INFORMATION

2.1 General

50 A.H. Cell fabrication document is comparable to the documentation and controls established by NASA for the Standard 20 A.H. Cells. At the present time only General Electric of Gainsville, Florida is approved as a source of NASA Standard Cells and has been used as the source of the 50 A.H. Cells.

General Electric manufacturers the cells in accordance with Manufacturing Control Documents 42B050AB20/21 Revision 7 and 232A2222AA-84 Revision 10. The catalog number assigned the regular cell is 42B050AB20, while the signal electrode cell number is 42B050AB21.

2.2 Plaque

The plaque from which the plate is made contains a perforated nickel-plated mild steel substrate. A porous nickel is attached to the substrate by passing the substrate through a slurry containing powered nickel-binder material mixture and subsequently through a sintering furnace. After sintering, the plaque is compressed and the plate coined areas are established.

Subsequent to the compression, the plaque is chemically impregnated with active nickel or cadmium materials.

2.3 Plaque Loading

Specified loading of the positive plaque is 12.5 $\pm$.6 grams/decimeter^2. This relatively light loading is beneficial in that it lessens the degree of plate growth and physical degradation characteristic of chemically impregnated positive plates. The negative plaque loading specification is 16.06 $\pm$.6 grams/decimeter^2.

2.4 Plates

There are sixteen positive plates and seventeen negative plates within a cell. The total positive plate area, including coined areas and excluding tab protrusions, is 22.75 decimeters^2 while the like area of negative plates is 24.17 decimeters^2.

The positive plates contain 5 percent cobalt hydroxide which reduces polarization, raises overcharge voltage level and thus improves plate charge acceptance. The negative plates receive a special Teflon treatment which aids oxygen recombination, retards cadmium migration through the separator and allows addition of more electrolyte.

2.5 Active Material Utilization and Positive to Negative Ratio

After detailed visual inspection and acceptance of the blanked plate, temporary flooded cells are assembled and tested to determine utilization of the active material impregnated into the plaque.

Experience to date indicates that 73-79 percent of the theoretical maximum capacity of the positive loaded material is realized during this testing. The utilization of the negative loaded material is 79-84 percent of the maximum theoretical.

The sealed cell capacity of the final room temperature acceptance test is approximately 96 percent of the positive plate capacity of the temporary (flooded) cell tests. The negative to positive recoverable capacity ratio based on the temporary cell test results is in a range of 1.83 to 1.86 for these cells.

2.6 Separator

The separator material is Pellon 2505 (nonwoven nylon) 10-11 mil as received and pressed to 7 to 8 mil thickness. An envelope formed from this material covers each positive plate. The cell pack, positive and negative plates, are wrapped as a unit with proplyene (10-11 mil thick) before case insertion.

2.7 Electrolyte

The electrolyte is thirty-one percent potassium hydroxide (KOH) aqueous solution. 170 millimeters of this solution are added to each cell at activation. The free volume within the cell is approximately 100cc.

2.8 Signal Electrode

The battery contains a signal electrode cell. The signal electrode is a cell within the case which senses oxygen pressure and, when externally loaded, outputs an analog voltage, between zero and one volt, which is proporational to the oxygen pressure it senses.

2.9 Cell Case and Header

The cell case is a welded design made from 304L stainless steel .028 inches thick. The heater is a brazed assembly of: 304L stainless steel cover; nickel 200 terminals, sleeves, caps and studs; alumina insulators; and 304 stainless steel comb. The ceramic to collar and stud braze is nickel-titanium while the collar to header braze is nickel-gold. The assembled cell is hermatically sealed and the terminals are insulated from the case. The terminals are pretinned by the cell manufacturer as a final step to facilitate soldering of intercell connectors.

2.10 Cell Capacity and Weight

The capacity requirement is 56.5 to 66.2 Ampere hours. Characteristically the cell capacity average during final room temperature acceptance testing based on cells for eight batteries was 60.7 Ampere hours and the average cell weight is 2014.2 grams.

2.11 Acceptance and Burn-In

The cells undergo 27 cycles in the preacceptance and acceptance test prior to delivery. Included in these cycles are:

a) Four formation cycles prior to precharge	....
b) Two pressure stabilization cycles post precharge	
c) Overcharge cycle	Preacceptance
d) Fifteen burn-in cycles	Test
e) Overcharge cycle	....
f) One 74°F cycle	
g) One 95°F cycle	Acceptance
h) One 32°F cycle	Test
i) One 74°F cycle	....

3.0 MECHANICAL INFORMATION

3.1 General

Figure 1 is an expanded drawing of the battery. In the figure the relationship of the mechanical components of the battery are shown. The battery "case" consists of two endplates, two channels, four tie rods, ten thermal fins, a connector bracket and the silicone potting. The assembly is lightweight, rugged and compact. The thermal fin assemblies serve a mechanical function in that the cell inertia loads are sheared into the fin upright members by the silicone bond and the loads are reacted at the fin gussets by the constraint of the holddown channels which are bolted to the mounting surface. The endplate design is a flat plate with integral ribs and frame. The flat side is next to the cells and transmits cell pressure load to the ribs and frame. The ribs and frame, in turn, transmit the load to the six tension members where the load is balanced by an equal load from the other endplate. A drawing of the battery envelope and mounting hole battery requirement is in the back of the manual.

3.2 Materials

A listing of the mechanical components and the material from which they are made is as follows:

Endplates	7075-T7351 Aluminum Alloy
Channels	7075-T7351 Aluminum Alloy
Tie Rods	303 Stainless Steel
Thermal Fins	3003-0 Aluminum Alloy
Connector Bracket	2024-T351 Aluminum Alloy
Silicone	RTV 560
Cells	See Cell Information

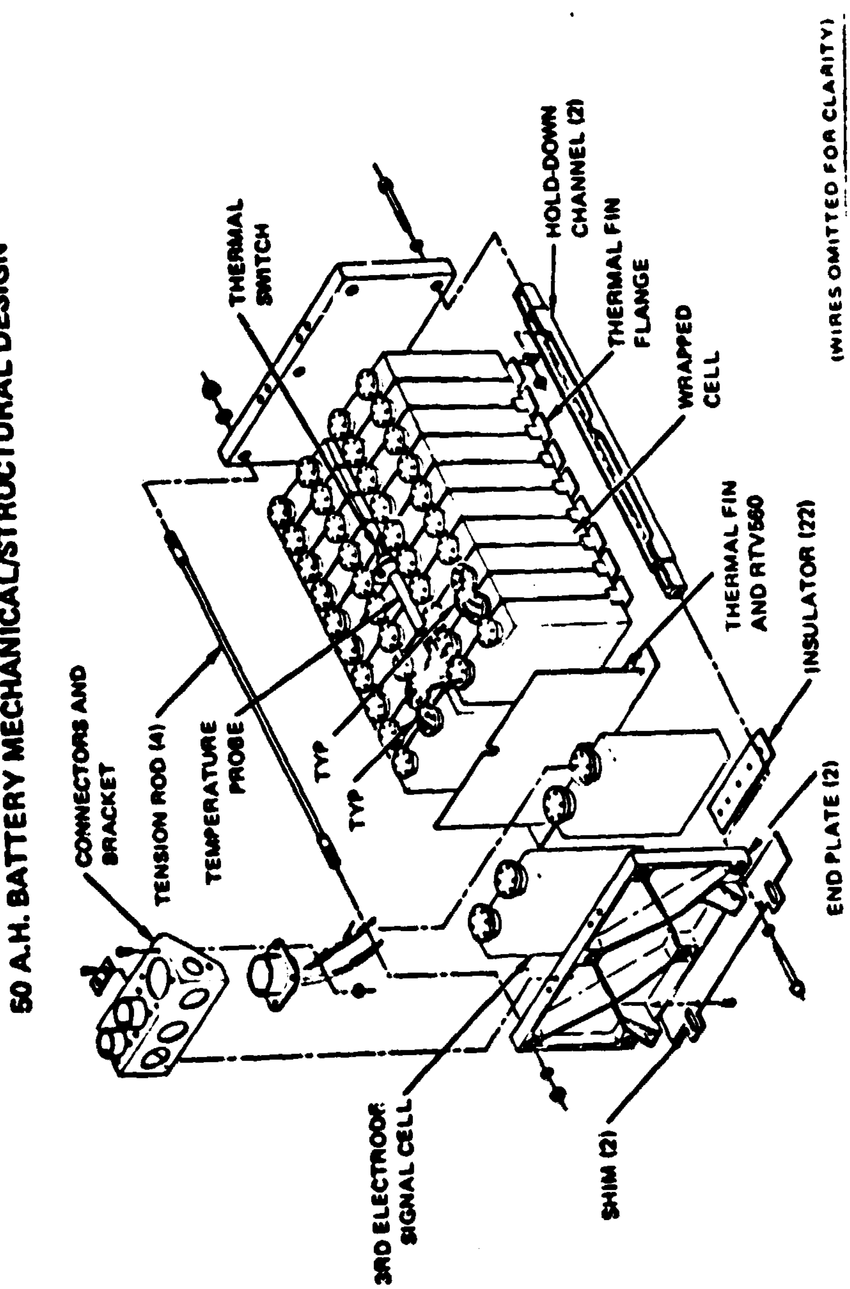

50 A.H. BATTERY MECHANICAL/STRUCTURAL DESIGN
CONNECTORS AND BRACKET
TENSION ROD (4)
TEMPERATURE PROBE
TYP
TYP
THERMAL SWITCH
HOLD-DOWN CHANNEL (2)
THERMAL FIN FLANGE
WRAPPED CELL
THERMAL FIN AND RTV560
INSULATOR (22)
END PLATE (2)
SHIM (2)
3RD ELECTRODE SIGNAL CELL
(WIRES OMITTED FOR CLARITY)

FIGURE 1

3.3 Assembly

Each cell header, terminal and pinch off tube, is protected by a machined phenolic block attached to the cell during the bonding process. All metal surfaces to be bonded are primed with GE SS4004 primer to assure good physical adhesion of the silicone potting. Two bonding tools are used in battery fabrication. One for individual cell bond and subassembly bonding and the second for all up battery bonding. Each cell is encased with 2.5 mil. thick glass cloth and silicone potting in the initial step of assembly. These bonded cells are next bonded into subassemblies, which contain one or two thermal fins and two or four cells. Height and base flatness are controlled during bonding by application of downward force to the phenolic blocks mentioned earlier.

The final battery bonding joins six subassemblies and two endplates. The resulting total potting thickness between a cell and an adjacent thermal fin is approximately .018 inches.

The bonded and cured battery is compressed by a 2300 pound force (34 lbs/in^2) and the tension members are tightened uniformly until the indicated share of the force applied by the machine decreases to approximately 2100 pounds. At this point the machine applied force is relieved.

Battery base flatness is measured and corrected as necessary to meet the .010 TIR requirements.

The electrical assembly consists of adding the instrumentation probe, thermal switch, intercell connections, connector bracket and wire harness to the bonded battery.

3.4 Mounting

The battery is attached with ten fasteners. The recommended hold down channel bolts are ST3M571 close tolerance flange head bolts with a 220 KSI rating. The recommended torque for these bolts is 40-50 inch pounds. The recommended endplate attachment screws are NAS 1531 Socket Head Cap Screws and the recommended torque is 15-20 inch pounds. Refer to the drawing in the back of the manual for the mounting hole pattern. The above recommendations are based on a maximum standoff of the battery to the mounting surface of no more than 0.1 inches, .063 inches of which are thermal fin base thickness.

3.5 Battery Weight Center of Gravity/Moments of Inertia

Completed battery weight is 112 pounds with the center of gravity very near the geometric center of the cell block. The Qual battery center of gravity and moment of inertia measurements are as shown in Figure 2. The products of inertia are insignificant.

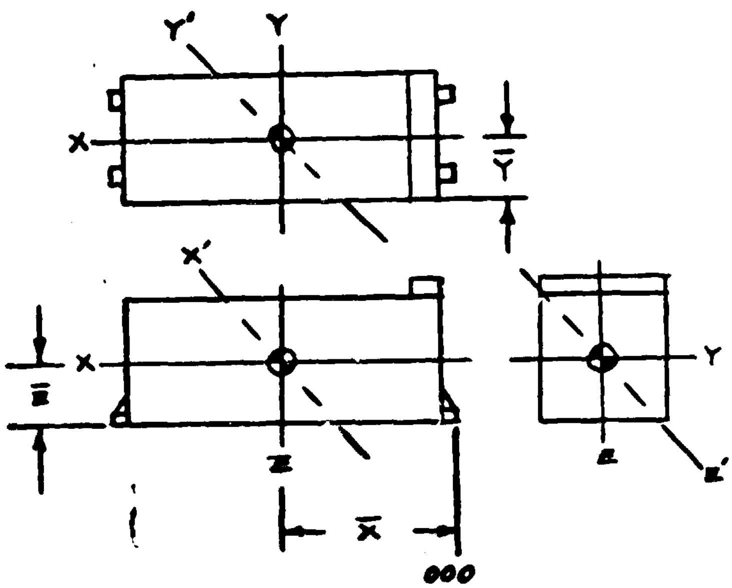


FIGURE 2

CENTER OF GRAVITY

$\bar{X}$ = 9.42 mm
$\bar{Y}$ = 5.82 mm
$\bar{Z}$ = -2.92 mm

MOMENTS OF INERTIA
THROUGH C.G. ABOUT
AXES INDICATED

I_X = .295 slug-Ft^2 I_Y = .587 slug-Ft^2 I_Z = .739 slug-Ft^2	MAJOR ORTHO-GONAL
$I_{X'}$ = .512 slug-Ft^2 $I_{Y'}$ = .437 slug-Ft^2 $I_{Z'}$ = .659 slug-Ft^2	45° CANTED

3.6 Battery Dimensions

The overall dimensions indicated on the drawing in the back of the manual are maximums.

3.7 Maximum Limit Loads

The maximum limit loads used to design the battery structure occur independently and are:

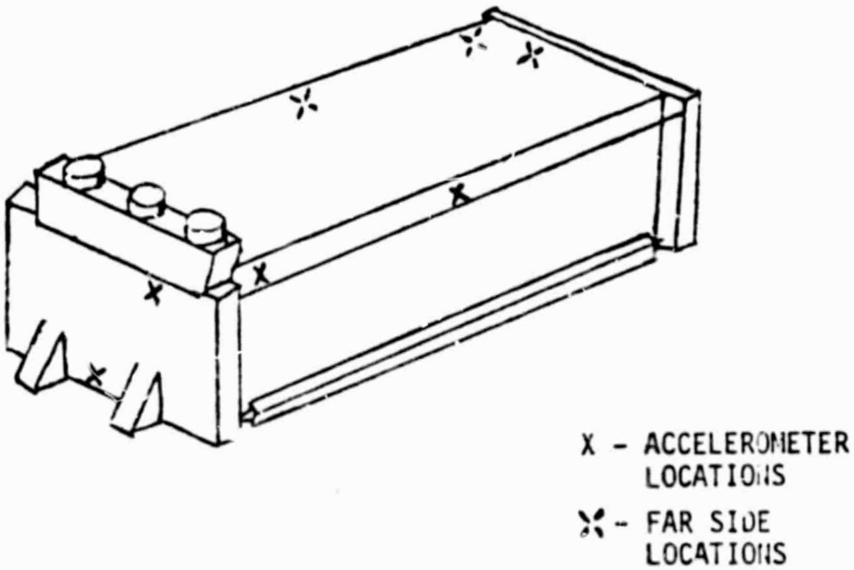
a) Internal cell pressure of 100 psi
b) Acceleration load of 33 g's applied along any of the three orthogonal axes in either direction
c) Vibration levels as indicated in paragraph 6.3
d) Shock levels as specified in paragraph 6.3.

3.8 Vibration Resonance and Amplification

The evaluation was conducted on the qualification battery instrumented with triaxial response accelerometers located as shown in Figure 3. The battery was mounted on a flatplate (1 inch aluminum) test fixture which was attached to the electromagnetic exciter system.

The peak transmissibility in the vertical test axis was 1.0 from 5 to 200 Hz. From the random data a fundamental frequency of approximately 360 Hz was indicated and the approximate amplification was 5. The peak transmissibility was 8.0 to 175 Hz.

The lateral random data had peaks at 230 to 250 Hz and the approximate amplification was 3.5. In the longitudinal direction the peak transmissibility was 8.0 to 175 Hz.



ACCELEROMETER LOCATIONS
DEVELOPMENT BATTERY EVALUATION

FIGURE 3

4.0 ELECTRICAL INFORMATION

4.1 General

Vendor acceptance performance records for the first time are used to select cells to be assembled into a battery. Standardizing cell fabrication has permitted the cost effective approach.

Silicone potting between the cell cases and the thermal fins or endplates accomplishes both mechanical and electrical objectives. Cell insulation from chassis and other cells is in the order of 10^6 megohms when tested at 100 VDC.

Twenty-two cells are electrically connected, after battery bonding, in a series string using solid tinned 10 gauge wire jumpers. Four jumpers, soldered between opposite polarity terminals on adjacent cells, provide strain relief, low resistance connection and ample current carrying capability.

Battery temperature sensor leads, signal electrode output, individual cell voltage sense leads and battery full and half voltage taps are routed to battery interface connectors to be used as condition indicators or battery control.

Unpainted areas are provided on the endplates for direct chassis grounding and battery chassis connections are routed through contacts on the power and signal connectors. The exposed areas, cell case tops, terminals and wire attachments are insulated (conformal coated) as the final manufacturing step in the battery assembly.

4.2 Cell Matching

Cells are selected for battery use based on their performance during cell vendor acceptance testing and their common plate log origin. The voltage and capacity performance during the 32°F and the second 74°F capacity cycles are the data evaluated in the process. Normally the cells are tested at the vendors facility in series connected groups of 25. Individual cell voltage and capacity variations from the group average are determined. These variations are then used to establish composite voltage and current distribution curves for the cells from the plate lot. A battery's cells are then selected according to their grouping on the composite distribution curves.

A typical example of the cell matching results are as follows:

BTRY S/N	PERCENT FROM 22 CELL AVG. 74°F CAPACITY HIGH CELL	74°F CAPACITY LOW CELL	32°F CAPACITY HIGH CELL	32°F CAPACITY LOW CELL	END OF CHARGE MILLIVOLT DIFFERENCE FROM 22 CELL AVG. 74°F VOLTAGE HIGH CELL	74°F VOLTAGE LOW CELL	32°F VOLTAGE HIGH CELL	32°F VOLTAGE LOW CELL
A006	+1.2	-1.2	+4.9	-2.3	+3.8	-5.2	+6.4	-5.6
A007	+1.7	-2.7	+2.4	-2.3	+4.3	-4.7	+4.5	-3.6
A008	+1.0	-3.3	+2.9	-2.8	+3.9	-5.1	+3.9	-6.1

4.3 Electrical Interface

There are three scoop proof MIL-C-38999 type connectors on the battery and the connector part no. pin number, gauge, and functions are as stated below:

(J1) Power Connector - LJTPQOORT-25-19S453 (BENDIX)

Pin	Gauge	Function	Pin	Gauge	Function
V	12	Power Return	C	12	Power Return
S		Power Return	K		Power Return
P		Power Return	H		Power Return
U		Power Positive	F		Power Return
R		Power Positive	D		Power Positive
N		Power Positive	L		Power Positive
T		Btry Chassis	J		Power Positive
E	12	Btry Chassis	G	12	Power Positive

Remainder with unterminated contacts inserted with seal plugs in the grommet holes.

(J2) Signal Connector - LJTQOORT-19-32S453 (BENDIX)

Pin	Gauge	Function
f	20	Cell 1 Positive
R		Cell 1 Positive
e		Cell 12 Negative
g		Cell 12 Negative
h		Cell 22 Negative
P	20	Cell 22 Negative

Pin	Gauge	Function
H	20	Btry + Sense
U		Btry + Sense
J		Btry - Sense
V		Btry - Sense
d		Signal Electrode Negative
c		Signal Electrode Positive
L		Platinum Resistor Terminal 1
K		Platinum Resistor Terminal 2
W		Platinum Resistor Terminal 1
X		Platinum Resistor Terminal 2
S		Thermistor 1 Terminal 1
T		Thermistor 1 Terminal 2
a		Thermistor 2 Terminal 1
b		Thermistor 2 Terminal 2
A		Thermistor 3 Terminal 3
B		Thermistor 3 Terminal 2
N		Thermal Switch Terminal 1
Y		Thermal Switch Terminal 2
M		Thermal Switch Terminal 1
Z		Thermal Switch Terminal 2
j	20	Btry Chassis Ground

Remainder with unterminated contacts inserted with seal plugs in grommet holes.

(J3) Test connector - LJTPQOORT-15-35S453 (BENDIX)

Pin	Gauge	Function
13	22	Btry (+)
15 Thru 25		Cell 1 (+) thru Cell 11 (+)
26 Thru 37		Cell 11 (-) thru Cell 22 (-)
14	22	Btry (-)

The 453 suffix in the connector part numbers assures the insert is a low outgassing material. The chassis of the battery has provisions for attachment of an external ground strap to the mounting surface.

4.4 Instrumentation

The instrumentation on the 50 A.H. Battery consists of a platinum resistor temperature sensor, three thermistor temperature sensors, a signal electrode in the most negative position cell, and a normally open thermal switch. The temperature sensors are potted into a .3 inch x 3.0 inch silicone cylindrical shaped probe which is subsequently bonded between the cells and abutting a thermal fin in the middle of the battery at cell top level. The platinum resistor is a Rosemount Engineering unit procured to a MDAC-StL source control drawing and has the following nominal characteristics:

Temperature	Resistance
-60°F	397.4 ±2.00 OHMS
-8	455.6
+32	500.0
+44	513.3
+96	570.5
+148	627.1
+200	683.4
+212°F	694.9 ±2.00 OHMS

The thermistors are Yellow Springs Instrument units and conform to NASA Goddard Specification S-311P-18. They have the following nominal characteristics:

Temperature	Resistance
-10°C	12.46K OHMS
0°C	7355 OHMS
+10°C	4482 OHMS
+20°C	2814 OHMS
+30°C	1815 OHMS
+40°C	1200 OHMS

The uniformity of the sensor indications is checked during battery acceptance testing at a stable temperature within ±2°C of a target temperature. The tabulated results from acceptance test S/N A0008 show sensor uniformity.

BATTERY STABILIZED TARGET TEMP	PT. RESISTOR TS1 Ω	TS1 TEMP	THERMISTORS TS2 Ω	TS2 TEMP	TS3 Ω	TS3 TEMP	TS4 Ω	TS4 TEMP
0°C	502.4	1.214	7017	.914	7018	.911	7018	.911
10°C	520.9	10.54	4426	10.26	4425	10.26	4426	10.26
20°C	539.8	20.05	2837	19.82	2836	19.83	2837	19.82

The thermal switch is a Sunstrand Data Control unit procured to a MDAC-St. Louis source control drawing. The switch has gold plated contacts suitable for low current circuit applications and closes at 35 ±1.7°C. Reopening occurs at 30.6°C minimum. The minimum dialband between closure and reopening is 2.2°C. The oxygen sensing signal electrode terminals are loaded, on the battery side of the interface, with a 200 ohm resistor. Figures 3A and 3B are typical of the electrode signal during a 24°C capacity cycle.

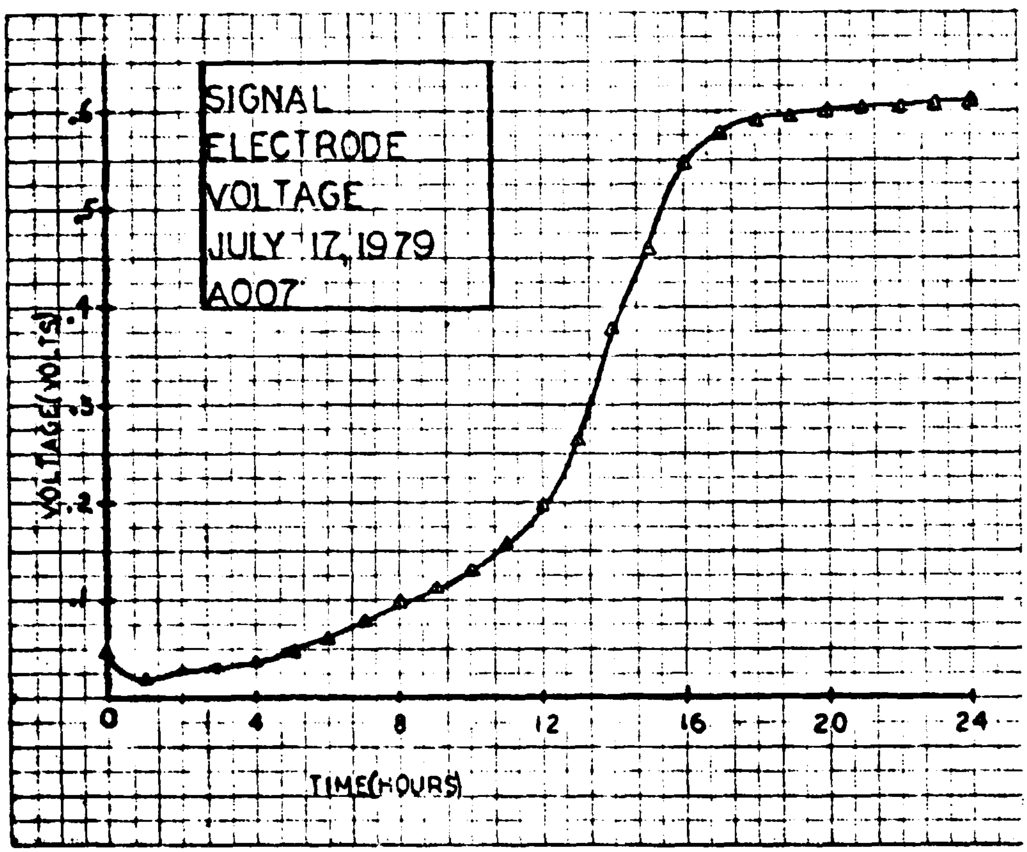


FIGURE 3A

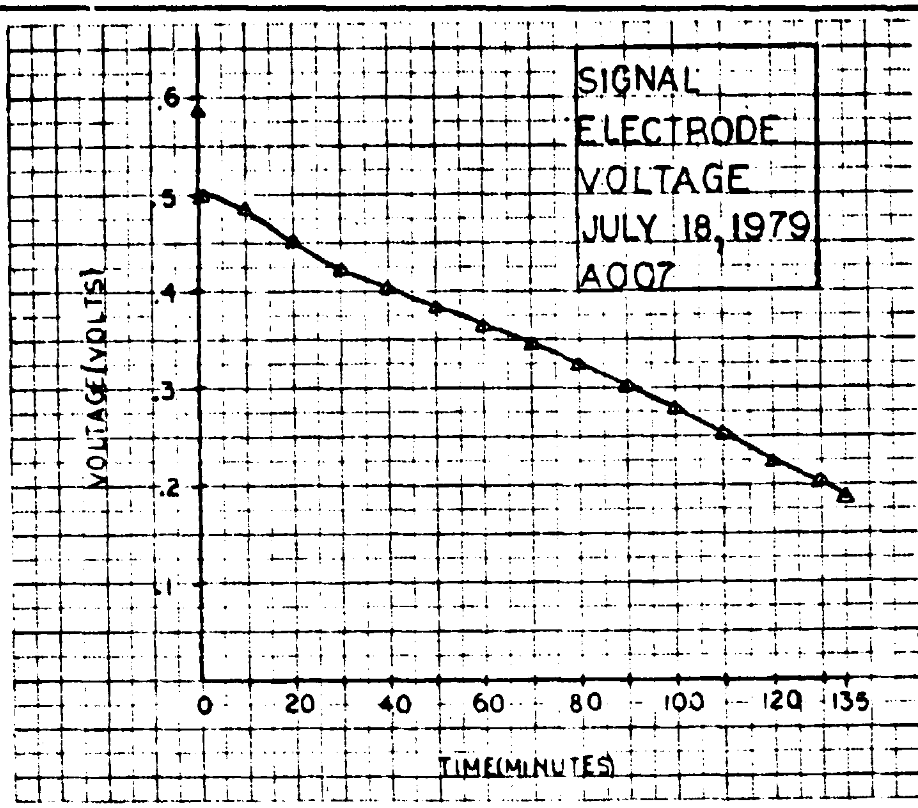


FIGURE 3B

4.5 Battery Capacity

A typical 24°C capacity profile for the 50 A.H. Battery is shown in Figures 4A and 4B. The capacities obtained from three 50 A.H. batteries are listed and are representative.

BTRY S/N	CAPACITY	% VENDOR CELL AVG CAPACITY
A006	54.75 AH	91
A007	55.78 AH	93
A008	55.40 AH	92

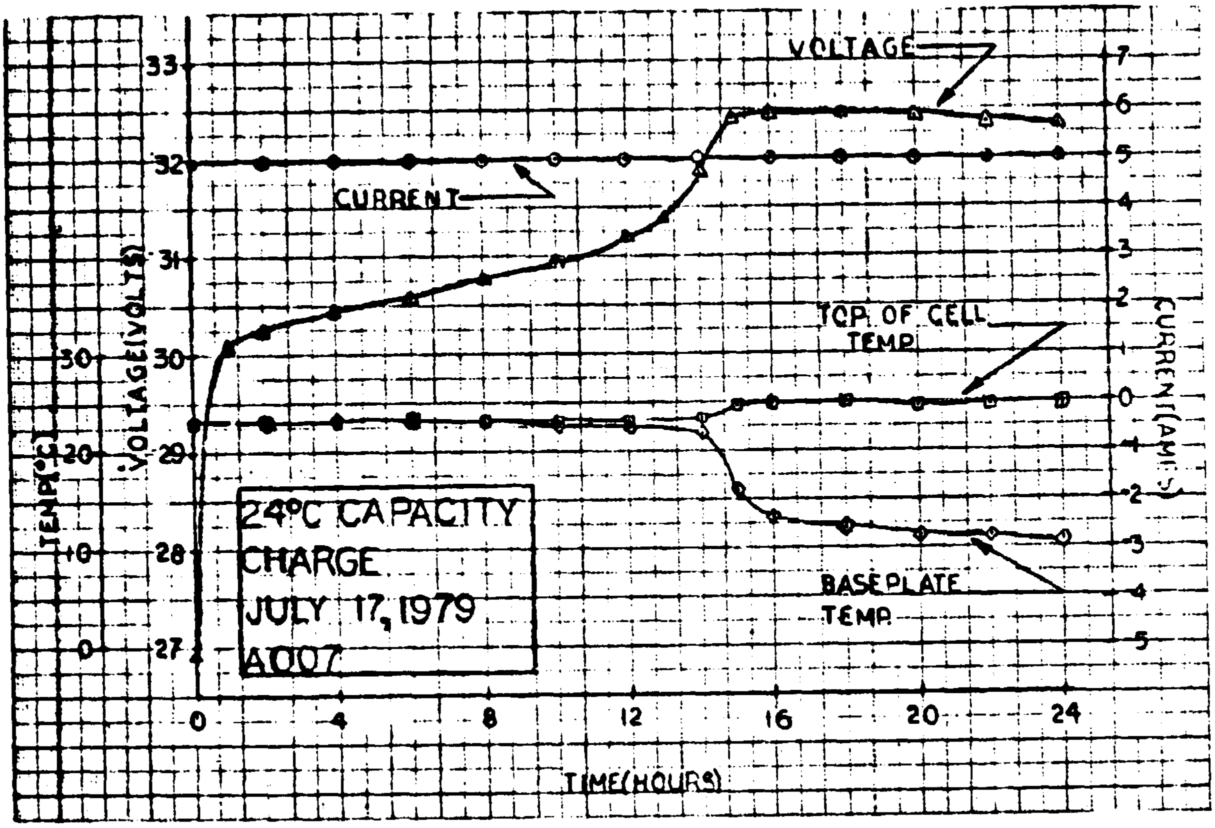


FIGURE 4A

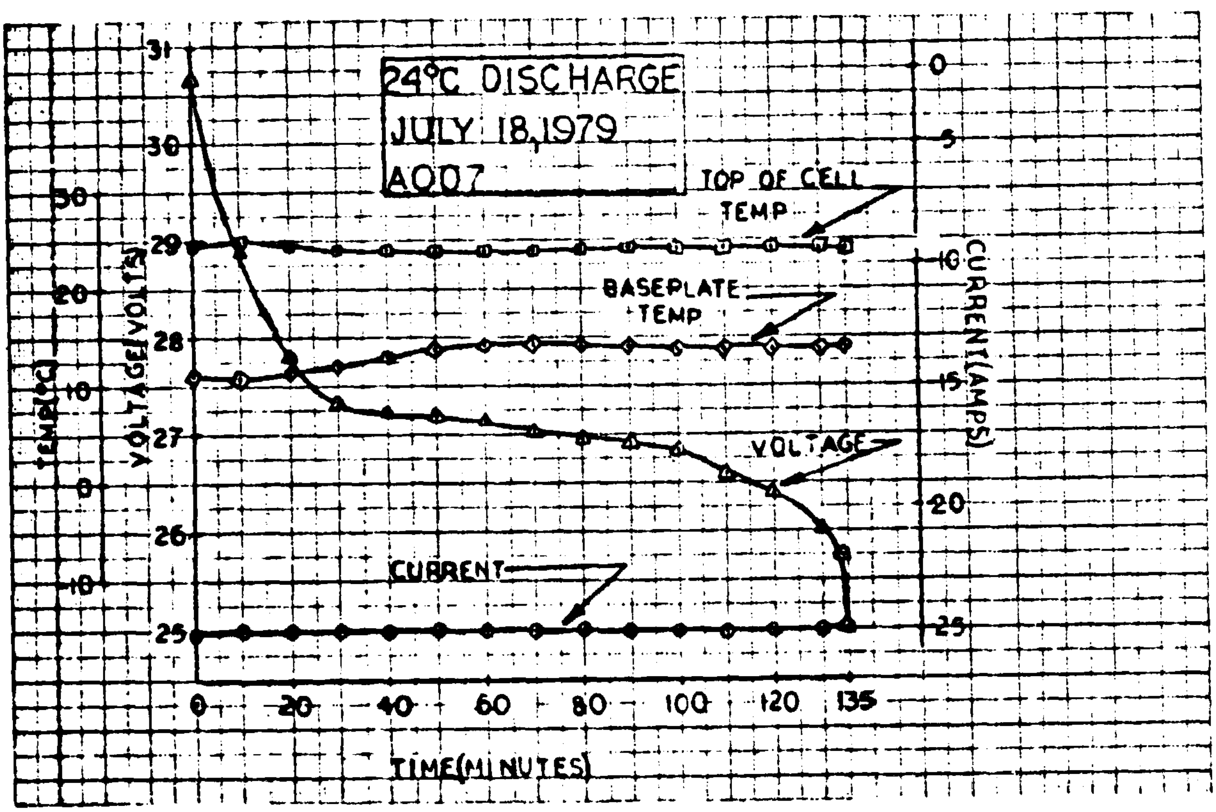


FIGURE 4B

A typical 10°C capacity profile is shown in Figure 5A and 5B. Representative capacities are:

BTRY S/N	CAPACITY	% OF INITIAL 24°C BTRY CAPACITY
A006	55.5 AH	101.5
A007	51.81 AH	92.9
A008	51.16 AH	92.3

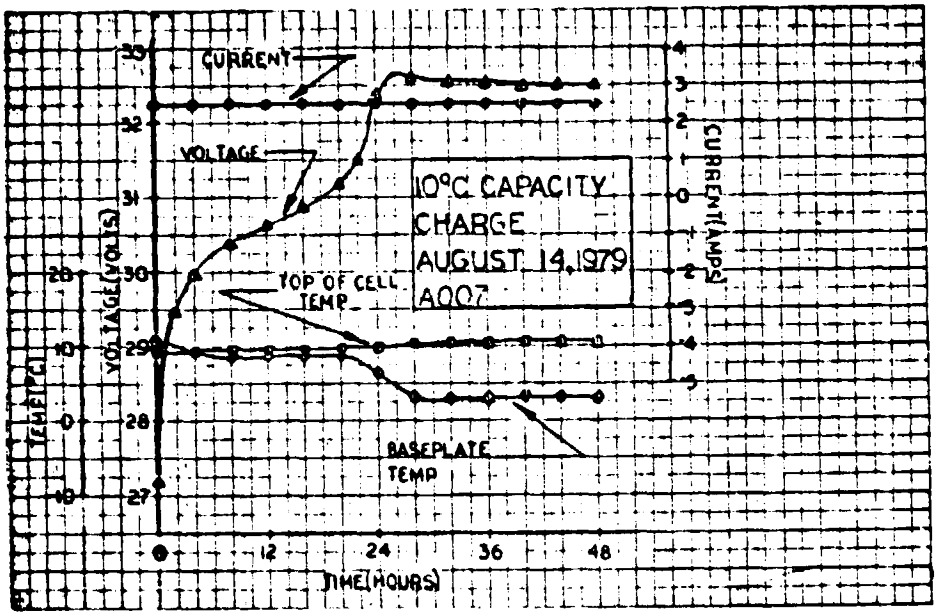


FIGURE 5A

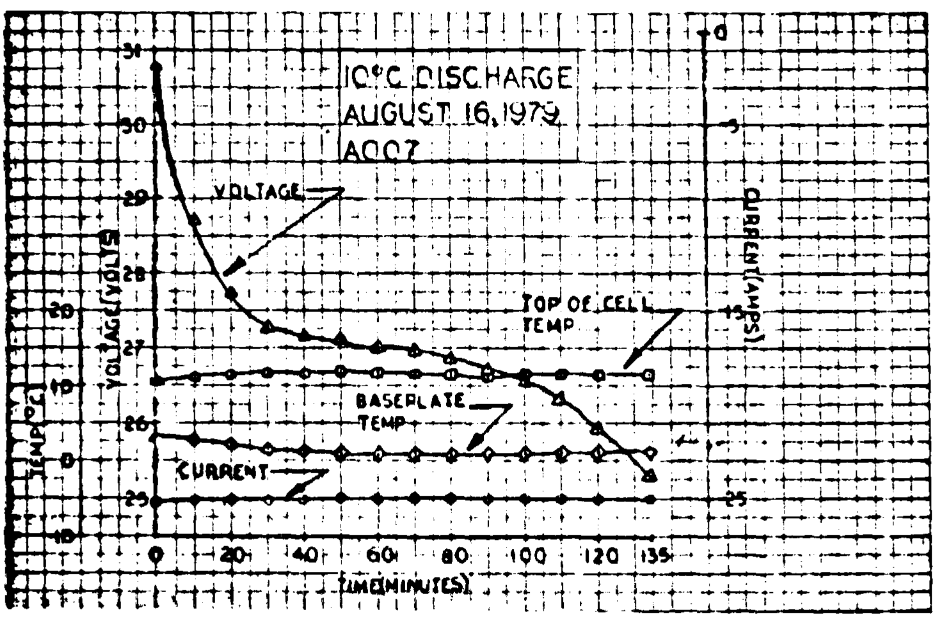


FIGURE 5B

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A typical 0°C capacity profile is shown in Figures 6A and 6B. Representative capacities are:

BTRY S/N	CAPACITY	% OF INITIAL 24°C BTRY CAPACITY
A006	52.49 AH	95.9
A007	51.59 AH	92.5
A008	49.11 AH	88.6

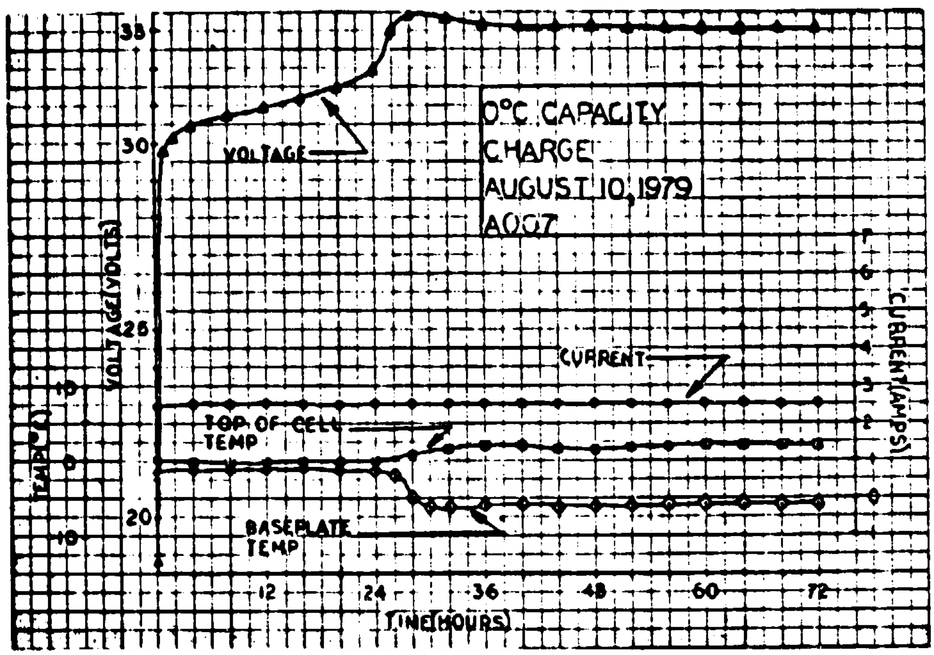

FIGURE 6A

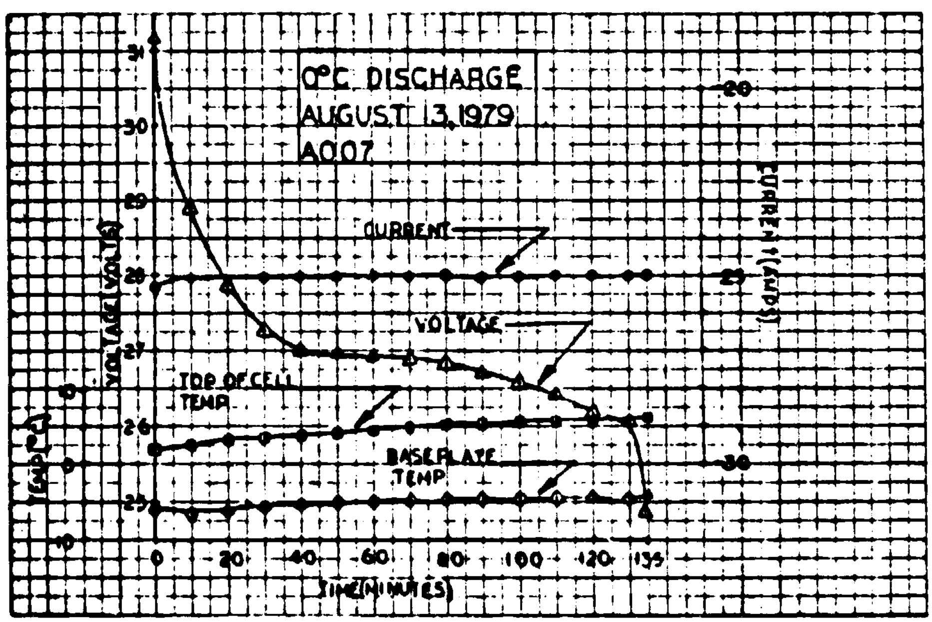

FIGURE 6B

4.6 Peak Load Performance

The Standard Battery performs well with high load current demands. During acceptance, the battery is subjected to a 5 minute load of 3C magnitude (150 Amperes) when it is at a 50 percent state of charge. The purpose of this test is to verify the integrity of all electrical connections within the cell and battery and disclose incipient separator weakness. The voltage and temperature response to the 3C load is shown in Figure 7. The calculated battery resistance ($\Delta V/\Delta I$) as a result of the 3C load application is 27 milliohms.

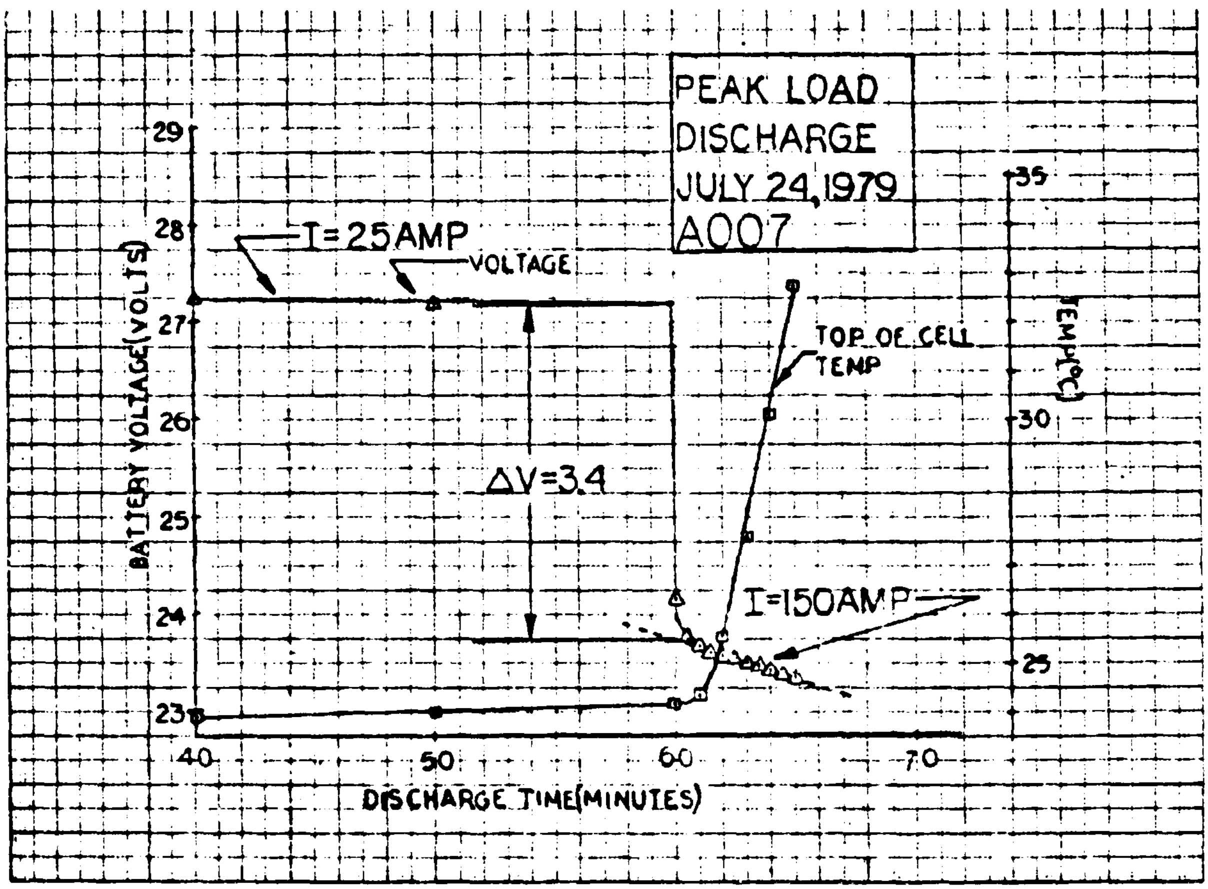

FIGURE 7

4.7 Orbiting Cycles and Charge to Discharge Ratios

Acceptance testing of the 50 A.H. Battery includes repeated 90 minute cycles at 25% DOD and 0°, 10° and 20°C mounting plate temperature. The batteries are in a 10^{-4} torr vacuum during these cycles. The cycling charge control routine begins with a constant C/2 charge current until the battery voltage reaches a preselected level (battery temperature dependent). From this point in the cycle until the next eclipse the voltage level is maintained and the charge current tapers. The discharge and recharge Ampere hours are measured and cycling continues until the charge to discharge ratio reaches stability.

Typical data taken from S/N A0007 from these cycles are presented in Figures 8A, 8B and 8C.

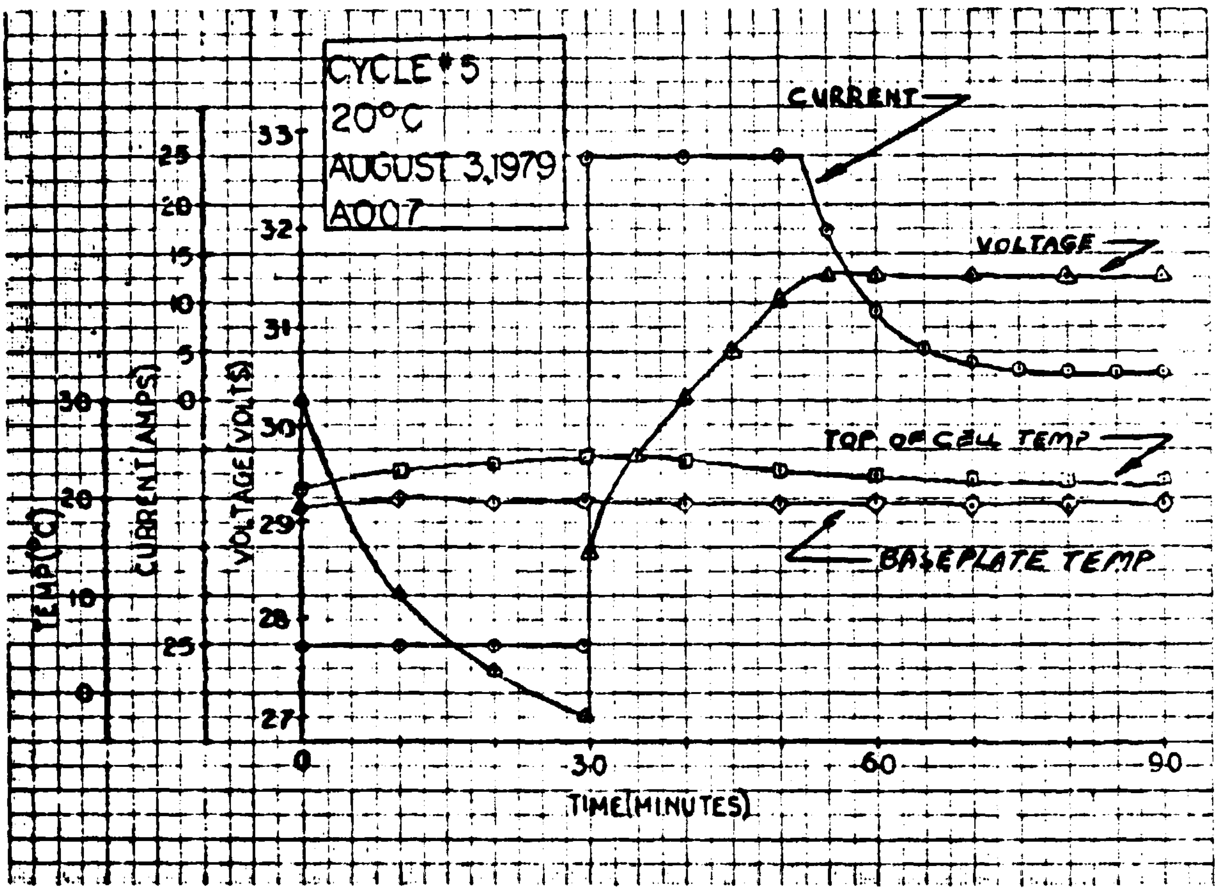

FIGURE 8A

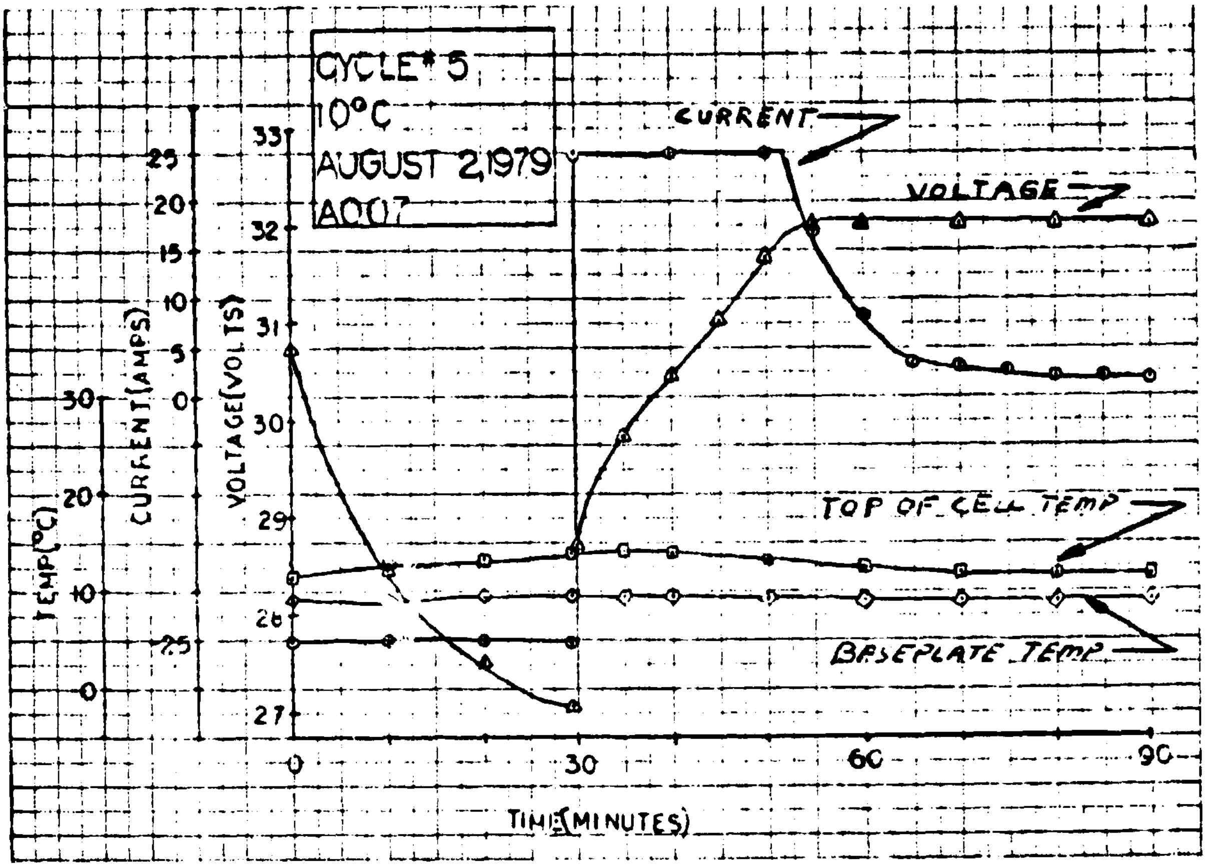

FIGURE 8B

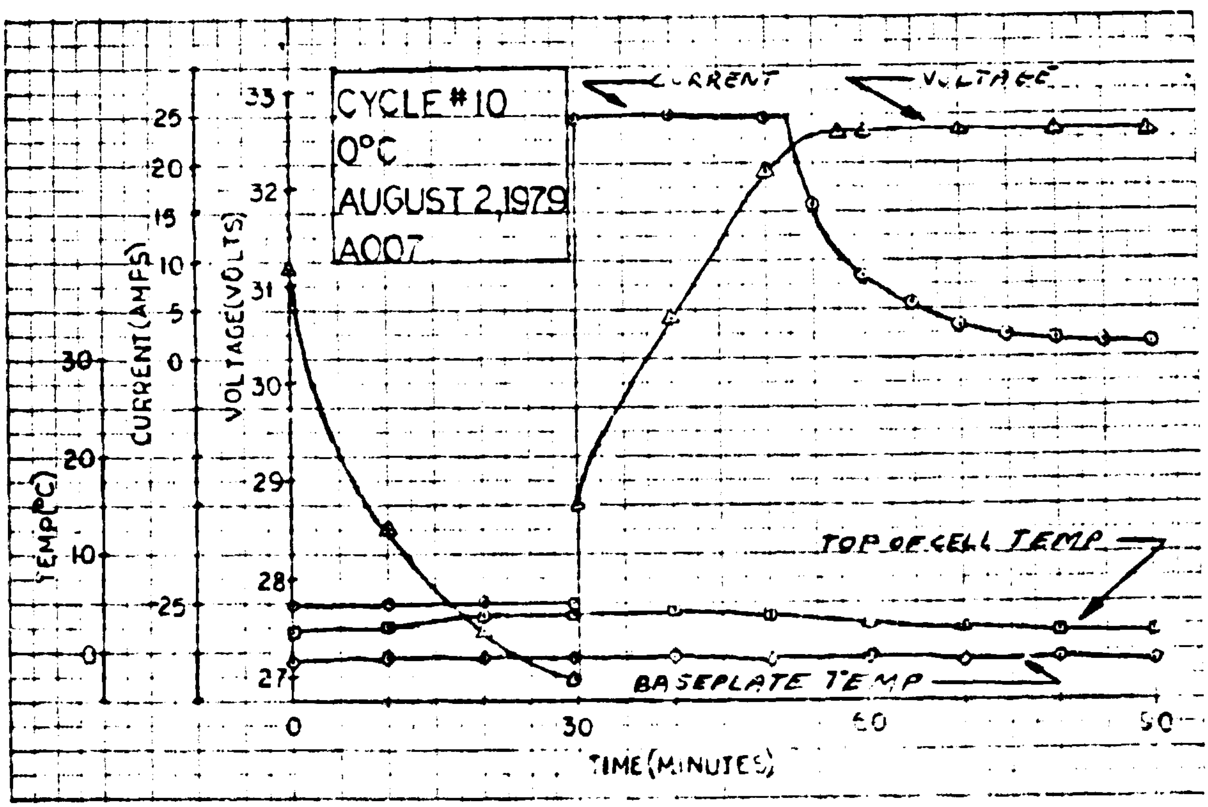

Figure 8C

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The charge to discharge ratios obtained during the cycling illustrated in Figures 8A, 8B, and 8C are as follows:

Temp	Voltage Level	DOD	C/D Ratio
0°C	6	25%	1.019
10°C	6	25%	1.036
20°C	6	25%	1.068

4.8 Battery Magnetic Properties

Batteries can contribute a considerable portion of a spacecrafts stray magnetic torquing moments if they contain large area wiring loops with appreciable current flow.

As can be seen in the introduction photograph, the 50 A.H. Battery contains five "crossovers" (crossed intercell connections) which create 2 pairs of opposing current loops and reduce the area of the odd loop such that the resulting dipole moment with a C/2 rate current flow is within the S-711-16 Rev A restraints.

5.0 THERMAL INFORMATION

5.1 General

The 50 A.H. Battery was designed to meet the thermal requirements of NASA Specification S-711-16, Rev. A and S-711-7, which are the battery specification and qualification specification respectively. The thermal fin volume, bonding thermal characteristics, base flatness, cell arrangement and paint characteristics were selected to accommodate the inefficiency reflected in Figure 9, NI-CD Battery Cycle Efficiency and to limit the thermal gradients within the battery to the 5°C top to bottom and 1.5°C difference in any plane parallel to the base when cycled at a 25 percent depth in near earth orbit.

5.2 Determination of Total Orbital Waste Heat Energy

Figure 9 illustrates the NASA Goddard recommended recharge Ampere hour ratios. These ratios have been required in NASA testing to maintain the battery at a proper level of charge consistent with uniform cell performance and long battery life. Total Orbital Waste Heat Energy (TOWHE) is derived from

Figure 9 information using a ratio of average charge voltage (30.8v) to average discharge voltage (28v) as a multiplier for the Ampere hour ratios. The watt hour return in excess of the watt hours delivered by the battery during eclipse is the TOWHE. In the initial application of the battery, for which MDAC-STL is responsible, a 30 percent depth of discharge was used in determining TOWHE.

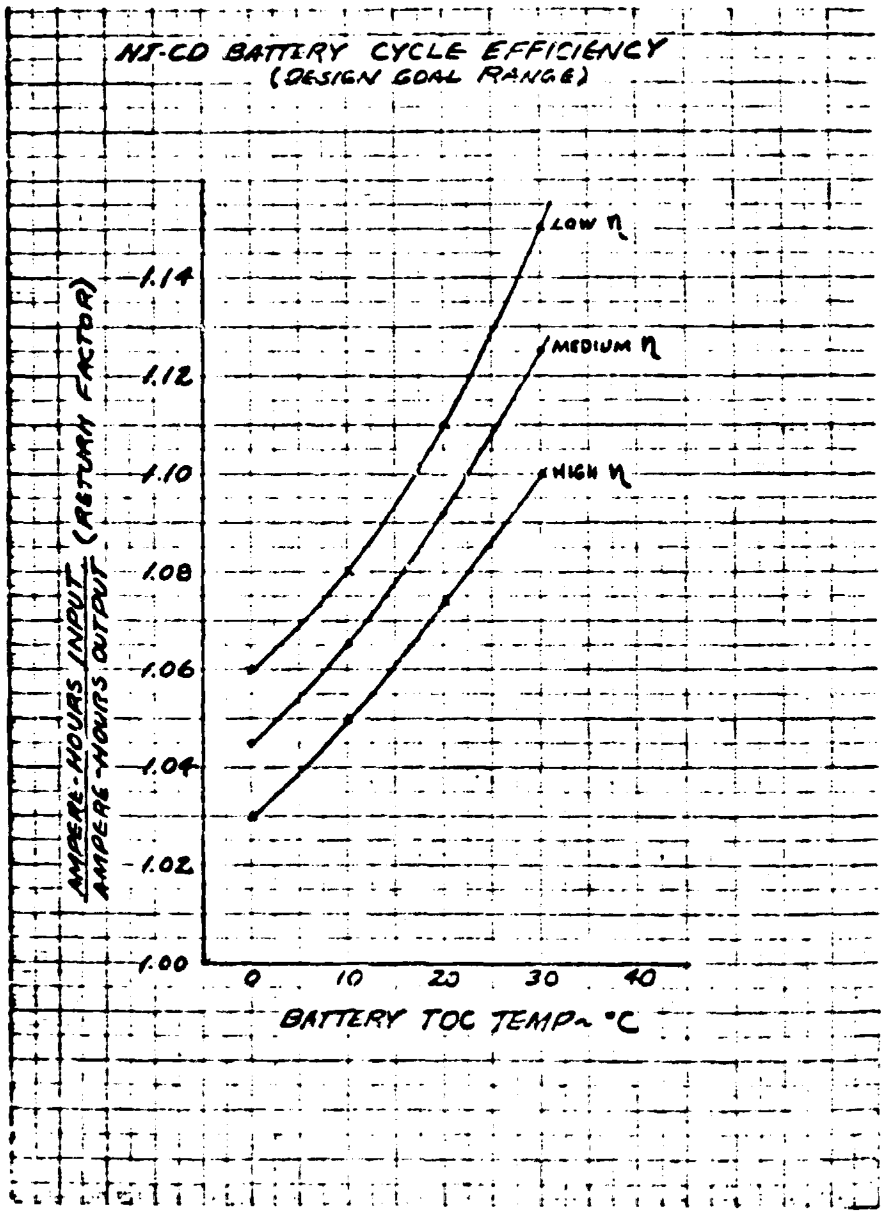


FIGURE 9

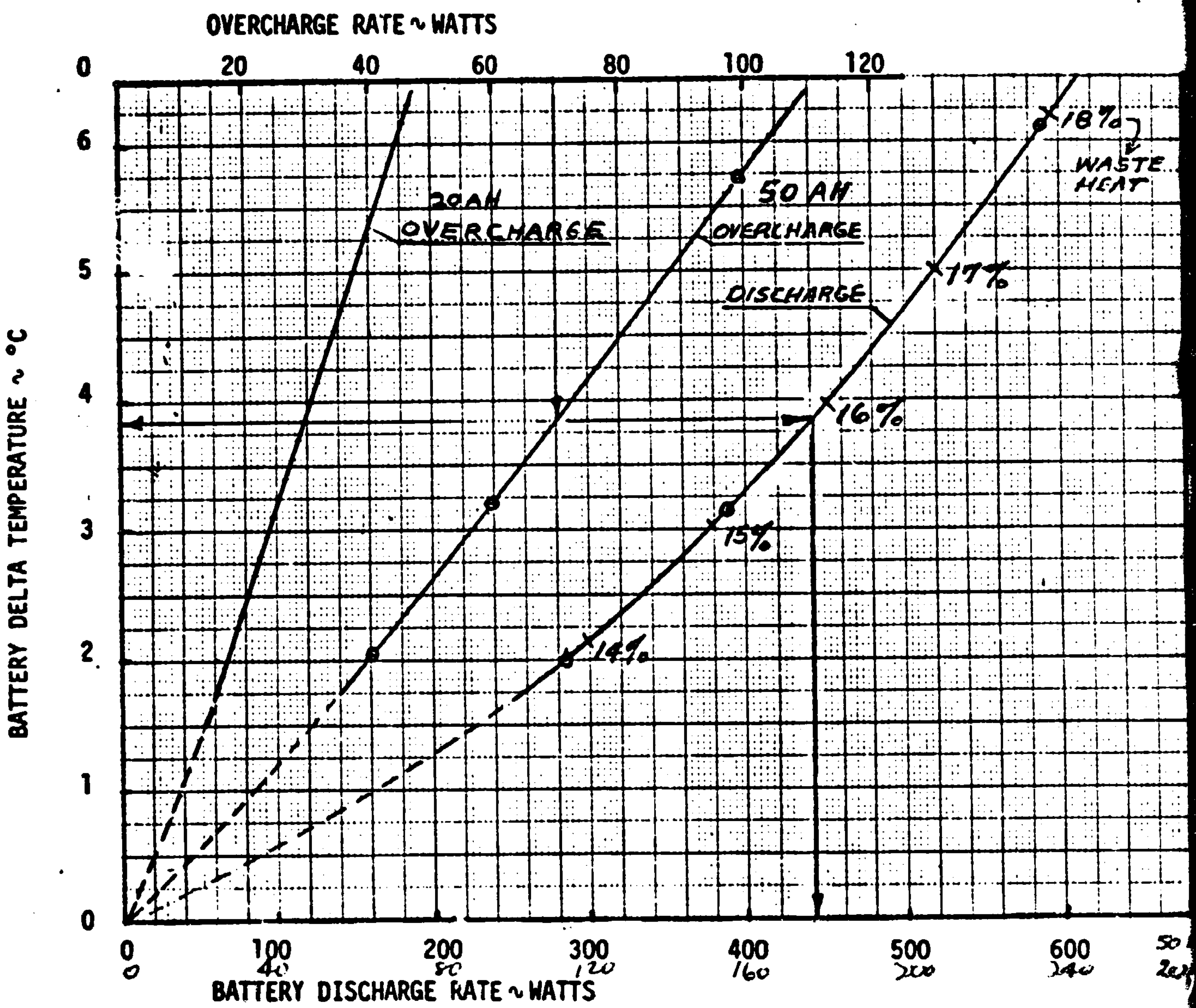

OVERCHARGE RATE ~ WATTS
0
20
40
60
80
100
120
20AH
OVERCHARGE
50 AH
OVERCHARGE
DISCHARGE
18%
WASTE HEAT
17%
16%
15%
14%
BATTERY DELTA TEMPERATURE ~ °C
0
1
2
3
4
5
6
0
100
200
300
400
500
600
0
40
80
120
160
200
240
BATTERY DISCHARGE RATE ~ WATTS

FIGURE 10

5.3 Characterization

Thermal tests were performed during the battery qualification process to characterize the battery's heat transfer properties during operation at different levels of battery overcharge activity. Gradient data were taken when temperatures in the battery had stabilized (< 0.1°C change in any monitored temperature for a period of one hour) at three specific levels of stable overcharge. The top-to-bottom gradient temperature relationship to the overcharge rates, thus found, were considerably less than those determined in a similar test on the 20 A.H. Standard Battery shown as the left curve of Figure 10. This is desirable and is reasonable with considering the increase in thermal fin cross sectional area for the 50 A.H. Battery. The evaluation of the results of the 50 A.H. Battery's heat transfer properties is presented in the middle curve of Figure 10.

Once the stable gradients were established for a given rate of overcharge the battery was immediately placed on discharge. The discharge load watts were selected and maintained by continuous load resistance adjustment during the battery voltage decay such that the various gradients remained constant. Correlation between overcharge watts and a percentage of discharge terminal watts using the differential temperature as a common scale was possible by this approach and is shown as the middle and right curves of Figure 10.

Discussion of Figure 10 relationships is covered in "50 A.H. Battery Qualification Tests (Thermal test runs per TCP 70A-127 paragraphs 6.8 through 6.16)." See Appendix A.

No attempt was made during this test series to obtain empirically the thermal storage constant either for the battery mass only or for the battery plus intimately connected cold-plate mass, since all significant test objectives were to be obtained at conditions of essentially zero heat storage within the battery. On the other hand, a storage correction was required to the raw data for Run #3, when the battery temperature had not yet become stable during the data-taking interval. In this instance, a storage constant for the 50 A.H. battery mass only was extrapolated from empirical data for a 20 A.H. battery and associated cold-plate mass, and used to correct the heat transfer data to a zero storage condition. This storage constant can be expressed in two different ways:

1. A storage rate of 10 watts will cause a battery bulk temperature increase of 1°C per hour.
2. Storage of 10 watt-hours of heat energy within the battery will cause a battery bulk temperature increase of 1°C.

The above storage constant is recommended for transient 50 A.H. battery analyses until such time as more accurate evaluations are made either analytically or empirically. The storage effects of closely associated cold-plate or radiator mass would be completely unique to each installation problem and are not treated here.

6.0 QUALIFICATION

6.1 General

The qualification tests to which the 50 A.H. Ni-Cd Standard Spacecraft Battery has been subjected are listed in Table 1. The battery has successfully passed these tests and is fully qualified.

6.2 Tests

Only those areas where ambiguity might exist or where levels are of interest are discussed below.

6.2.1 Capacity Tests

The battery top of cell temperature was maintained at the test temperature during charge and discharge. All discharges were conducted at the C/2 rate and were terminated when a 1.0 volt per cell average was reached or any cell reached 0.5 volts. Charging currents and durations were as follows:

Test Temp	Charge Rate	Duration
24°C	C/10	24 $\pm$1 Hr.
0°C	C/20	72 $\pm$1 Hr.
30°C	C/10	24 $\pm$1 Hr.
10°C	C/20	48 $\pm$1 Hr.

TABLE 1

QUALIFICATION TESTING

Functional Tests
- Temperature Sensor Operation
- Thermostatic Switch Operation
- Insulation Resistance
- Conditioning
- Leak Test
- 24°C Capacity
- Charge Retention
- Peak Load

Vibration Shock

Function Tests (As Above)

Thermal Vacuum
- Cycling
- Thermal Characterization

Capacity Tests

Final Performance
- Charge Retention
- Peak Load
- Temperature Sensor Operation
- Thermostatic Switch Operation
- Insulation Resistance
- Leak Test

Magnetic Properties

Physical Measurements

6.2.2 Charge Retention

This test was an open circuit, 24 hour voltage recovery type following 16 hour period of 1 ohm per cell shortout. Criteria was minimum of 1.17 volts per cell.

6.3 Vibration/Shock

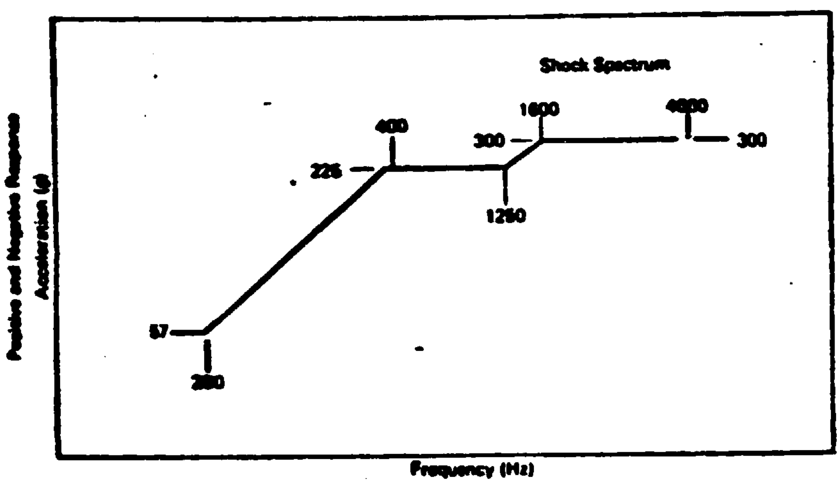
Sinusoidal vibration was conducted along each major orthogonal axis at following levels:

Freq Range (Hz)	Level (Stated)	Sweep Rate (Oct/Min)
5-28	1.27 CM da	2
28-50	20 g	2
50-75	10 g	2
75-200	.5 g	2

Random vibration was conducted along each major orthogonal axis for 2 minutes. Vibration was as follows:

Freq Range (Hz)	PSD (g^2/Hz)	Acceleration (g rms)
20-800	0.5	27.5
800-2000	-3 db/OCT	

Shock tests were along each major axis to the following spectrum level.



6.4 Thermal Vacuum

These tests were conducted at 10^{-5} torr with chamber walls at lab ambient temperatures.

6.4.1 Cycling

During cycling the battery top of cell temperature was controlled to the test temperature. Depth of discharge and voltage limit levels were as listed during the 30 minute discharge/60 minute charge cycles.

Test Temp	DOD %	CHG Volt Limit	BT Level
-10°C	10	1.483	5
-10°C	25	1.503	6
+10°C	25	1.457	6
+10°C	40	1.477	7
+25°C	25	1.422	6
+25°C	40	1.442	7

6.4.2 Characterization

The test method is outlined in Section I of Appendix A.

6.5 Humidity

This test is not performed for the 50 A.H. Battery. The response is the same as the humidity test performed on the 20 A.H. Battery.

7.0 ACCEPTANCE

Acceptance tests are similar in scope to the qualification tests of paragraph 6. Differences are enumerated in following sub-paragraphs.

7.1 Vibration/Shock

The levels of exposure during sinusoidal and random vibration are decreased to two thirds of the qualification levels and the durations are decreased by 50 percent. Shock testing is not performed as an acceptance test.

7.2 Thermal Vacuum

Battery cycling in the acceptance test is performed at 0°, 10°, and 20°C and only at 25 percent depth of discharge. Voltage level 6 is used during acceptance cycling and battery base plate temperature is controlled to the test level.

/

7.3 Capacity Tests

Acceptance capacity tests are conducted at 0°, 10° and 20°C.

7.4 Magnetic Properties

This test is not performed in acceptance process.

7.5 Humidity

This test is not performed in acceptance process.

7.6 Physical Measurements

Determination of Center of Gravity and Moments of Inertia is not required in the acceptance process. Weight and dimensional measurement are performed.

8.0 LIFE TEST

Near-earth and synchronous life testing is being planned by NASA Goddard in conjunction with Naval Weapon Support Center (Crane, Indiana). Several 50 A.H. cells have been obtained by Naval Weapon Support Center. Any testing will be at the direction of NASA Goddard.

9.0 SUPPORT AND HANDLING EQUIPMENT

Support equipment (70D233010) is provided with each battery for protection of the battery heat transfer surface, cell terminals, instrumentation and battery wiring during periods of battery handling. A shorting connector (70D237108), which maintains each cell in hard shorted condition, is also provided. A battery, so protected, and shorted is packaged for shipment in a reusable container (SC70A233008-501TD). The shipping container has temperature recording provisions internal to the outer box. The temperature recorder is a seven day recorder and provides a record of temperature profile throughout the period. The inner box of the shipping container houses the battery, protective covers, and shorting plug which are wrapped as a unit with a sealed anti-static wrap (MIL-B-81705 Class A). Within the inner box, and external to the plastic wrap, are 184 units of MIL-D-3464 Type II, nondusting desiccant. The inner box is covered with a MIL-B-131 moisture barrier which is evacuated and heat sealed. The inner box, so sealed, is suitable for battery storage at 5°C ±5°C.

10.0 HANDLING AND STORAGE RECOMMENDATIONS

10.1 General

The following recommendations address storage and operational handling of all 50 A.H. Ni-Cd Batteries. The difficulty of rigid adherence to these recommendations for batteries installed in the using vehicle during checkout activities is recognized. For this reason, it is imperative that nonflight batteries serve as the power source during such activities and flight batteries be installed late in the launch preparations.

10.2 Storage

The recommended condition of battery storage, to assure minimal effect on its life and rate of performance degradation, is fully discharged with each cell individually shorted. Storage environment selection depends on whether the battery is installed or is being bench tested.

10.2.1 When to Store (Bench or Vehicle Installed)

Where it is determined a charged battery will be inactive for a period approaching a week, it is recommended the battery be discharged and the shorting plug installed until the scheduled usage at which time a regular C/10, 24°C 24 hour recharge should be performed.

Where the anticipated inactive period exceeds a week and approaches 30 days, consideration should be given to placing the discharged and shorted batteries in a dry (<40% relative humidity), cool (5°C ±5°C), storage area. Where the batteries are installed in a vehicle, an alternate to the above recommendations is to continually trickle charge and batteries during inactive period at a C/60 rate. Where the inactive period exceeds 30 days, the dry and cool storage should be used.

10.2.2 Removal From Storage

Batteries removed from cool storage should be allowed to stabilize at room temperature and precautions taken to preclude condensation accumulation. The recharge conditions are dictated by the length of battery inactivity. Special conditioning, C/20, 24°C, 48 hour charge and regular discharge, is required prior to the normal recharge if the period of inactivity exceeds 15 days.

10.3 Routing Installed Operation

Battery open circuit time should be minimized as it is deleterious to batteries. Where open circuit periods exceed four hours the battery should be discharged at a low rate (nominal spacecraft loads) for 2 to 5 minutes prior to attempting to charge. This will preclude slight hydrogen generation during initial moments of charge.

Operational time periods in excess of 14 days, where the battery(ies) have not been fully recharged and where their state of charge, due to random discharge and partial recharge cycles, is uncertain should be treated as follows:

a) Battery voltage under moderate load of <26.4 volts dictates a complete discharge (C/2 rate to 1.0 volt/cell average or any cell <.5 volts) and

1 ohm shortout of each cell for 16 hours followed by a C/10 recharge for 24 hours. CAUTION: Battery temperatures will rise during C/2 discharging and will also rise after approximately 14 hours of the C/10 charge. Cooling must be provided to maintain battery temperatures below 30°C. CAUTION: Battery discharging below terminal voltage of 25.75 volts with C/2 rate should only be attempted with individual cell monitor capability. Without this capability, the discharging should be terminated at 25.75 volts and each cell should be individually loaded with a 1 ohm resistor. Resistors should remain in place until battery terminal voltage is <3.3 volts.

b) Battery voltage under moderate load of >26.4 volts may be discharged for 2 to 5 minutes at the moderate load rate and then recharged at constant current charge (C/4) to voltage limit based on level 6 of S-711-16, Rev. A and then continued at that level until the current tapers to approximately C/10 level.

DEFINITIONS

Substrate	A .004 inch thick and seven inch wide mild steel strip which is approximately 85 percent perforated and subsequently nickel-plated.
Plaque	A substrate length which has porous nickel sinter attached and which is subsequently impregnated with active nickel or cadmium material.
Impregnation	Chemical process of inserting active material in the pores of the plaque nickel sinter.
Loading	The measure of active material chemically inserted in a given area of plaque. Generally given in grams per decimeter squared.
Plate	A processed portion of plaque containing an intergral non-sintered tab for attachment of cell terminal. Processing is a blanking operation where plate is cut to required shape.
Separator	Nonwoven nylon material used as electrolyte wick and electric insulator between positive and negative plates within a cell.
DOD	Depth of Discharge: Percentage of the given rated capacity of the Battery.

APPENDIX A

50 A.H. Battery Qualification Tests

(Thermal Test Runs per TCP TR 70A-127

Paragraphs 6.8 Through 6.16)

50 AH BATTERY QUALIFICATION TESTS (THERMAL TESTS RUNS PER TCP-TR70A-127 PARAS 6.8 THRU 6.16)

I. DISCUSSION OF RESULTS

Thermal tests were performed to determine battery heat transfer characteristics during operation at three different levels of battery activity. Testing procedure was per TCP-TR70A-127 except in two areas. First, the overcharge rate for Run #3 was increased from 80 watts up to 100 watts after it became evident from the two previous runs that top-to-bottom temperature differentials were not as large as predicted, and might not reach the design maximum value of 5°C during the tests. Second, the tolerance on battery fin temperature levels in demonstration of thermal balance were tightened to a goal of no more than 0.1°C change in a one hour period, in order to effectively zero out any battery heat storage or unstorage. In Run #3 this goal was not achieved, and it was necessary to apply a correction for battery storage.

The stable overcharge phases of the three test runs were used to "calibrate" the battery top-to-bottom heat transfer characteristic, i.e., to obtain battery vertical temperature differential as a function of the rate at which heat is being generated within the battery and removed at its base. To be most accurate, this calibration requires conditions of zero heat storage within the battery. This was implemented during the tests by requiring battery temperature stability at several locations in the battery to 0.1°C for a period of 1 hour before a stable data point was taken. Having thus calibrated the battery, this calibration could then be used to derive battery efficiency during discharge over a range of power rates. Battery "efficiency", or more correctly, "inefficiency", was calculated from the measured data as the ratio of waste heat rate to delivered power rate, expressed as a percentage. A summary of the more significant data results is presented in Table 1 and plotted as Figure 1.

BATTERY HEAT TRANSFER CALIBRATION - Top-to-bottom temperature differentials measured at the centerline of the middle thermal fin are seen (Fig. 1) to vary essentially linearly with waste heat rate over the range of heat rates from 40 to 100 watts, reaching a delta temperature of 5.7°C at the higher value. This is 77% of the predicted value programmed into the MPS 50 AH module computer model, and provides a comfortable margin in vertical heat transfer capability with this battery design. Battery overcharge power and temperature level stability during the calibration phase met the test procedure requirement. The more significant parameters are plotted in Appendix A, where zero time for all curves is the beginning of the stable overcharge test phase. Tabulated values for all test measurements are on file in the Test Data Report. Selected balancing values at the ends of the overcharge runs are presented in Tables 1, 2, & 3.

BATTERY DISCHARGE EFFICIENCY - A summary of the more significant discharge data results is presented as the lower half of Tables 1, 2, & 3 and plotted as the right-hand curve of Fig. 1. Each discharge run followed immediately an overcharge run, and its discharge power rate was calculated to produce the same waste heat rate as the preceding overcharge run. If the calculated power rate did not hold all battery temperature levels stable, then the discharge rate was changed to find a level which would stabilize the battery at thermal conditions as close as possible to the stable overcharge conditions. The test procedure allowed 2 hours of discharge time in which to obtain a stable operating point. A stable operating point which did not match exactly the preceding overcharge point, can be compared to a corresponding delta temperature point of the calibration curve generated during the overcharge phases (left-hand curve of Figure 1.) The tic marks on the battery discharge rate curve are the battery waste heat rate as a percent of the battery discharge power rate. Runs 1 and 2 were operating at about 14 & 15% waste respectively while Run 3 showed over 18% waste. Battery top-of-cell temperature during Run 3 was 23.6°C compared to 20.6 & 20.8°C during the other two runs, so the higher temperatures may have caused the higher waste. The power rate during Run 3 was considerably higher also, but there is no documented justification for this as a cause for reduced battery efficiency.

The apparent high sensitivity of battery discharge efficiency to battery top-of-cell temperatures over 20°C is not inconsistent with the data points from the 20 AH Battery Development Tests, plotted on page 27 of TN #16. The effects of temperature in this range on efficiency should be tested further for constant discharge power rates at the approximate 500 watt level.

The process of adjusting discharge power rate early in the discharge phase to a value which balances battery temperature levels at preselected values is a difficult part of the overall test procedures. It is achievable, however, as demonstrated in Run 2 where the initial discharge power setting was simply scaled up (at the same efficiency) from the balancing value measured in the preceding Run 1, and did not require change for the entire discharge phase of over 2 hours. Run 3, on the other hand, exhibited a higher percentage waste heat than Run 2 so that the initial scaled power rates were much too high for balance at the desired temperature level. Even though power rates were subsequently reduced, full balance had not yet been achieved, even after over 2 hours of discharge, so that a correction of 21.4 watts was required to the measured power rate to account for a battery heat-up rate of 0.4°C per hour during the "balance" period.

<u>BATTERY TEMPERATURE DISTRIBUTION</u> - Table 4 shows typical temperatures thru out the battery and cold plate during charge and discharge test phases.

II. CONCULSIONS & RECOMMENDATIONS

1. Measured top-to-bottom delta temperatures were 77% of design (predicted) values @ 589 watts discharge power rates.
2. Waste heat rates varied between 14% of battery discharge rate at 284 watts power rate & 18% at 589 watts power rate.
3. The testing procedures used to calibrate the battery as a heat transfer rate "calorimeter" produced by heat flow within the battery, based on top-to-bottom temperature differentials, are simple to apply and gave consistent results. This may prove to be the most effective technique by which to measure the rate of heat removal from a cold-plate-cooled battery.

4. The techniques and calibration of Item 3 above were applied to battery constant-power discharge conditions, to obtain a measure of battery discharge efficiency. Efficiency measured during Run 3 was markedly lower than during Runs 1 & 2. This may have been due to higher temperature levels (Δ2.6°C), or to higher discharge power rate, or both. Future runs to delineate the individual effects of power rate and temperature levels above 20°C on battery efficiency are recommended.

TABLE 1

BATTERY THERMAL BALANCE CONDITIONS

-- THERMAL QUALIFICATION TESTS --

	RUN NUMBER 1	RUN NUMBER 2	RUN NUMBER 3
OVERCHARGE PHASE			
CHARGING POWER RATE ~ WATTS	40.1	59.6	100
COLDPLATE TEMPERATURE ~ °C	17.9	16.9	16.1
BATTERY TOC TEMP ~ °C	20.5	20.8	22.8
BATTERY TEMP ~ °C	2.0	3.2	5.7
DISCHARGE PHASE			
DISCHARGE POWER RATE ~ WATTS	284	389	588 *
BATTERY TOC TEMP ~ °C	20.6	20.8	23.6
BATTERY TEMP ~ °C	2.0	3.1	6.1
% WASTE HEAT	13.9	15.1	18.0

* NOT BALANCED, BUT CORRECTED FOR BATTERY HEAT STORAGE AT A 4-WATT RATE

TABLE 2

RUN #1, DAY 80, 40 WATTS NOMINAL WASTE

	TIME	WATTS	℄ TOC CH 45	℄ MOC CH 48	℄ BOC CH 51	COLD PLATE CH 60	COOL IN CH 62	TEMP TOP TO BOTTOM
I OVERCHARGE PHASE:								
END	18:10	40.3	20.5	20.3	18.5	17.9	16.6	2.0
	18:00	39.4	20.5	20.3	18.4	18.0	16.7	2.1
	17:50	39.7	20.5	20.3	18.4	18.0	16.6	2.1
	17:40	39.2	20.5	20.3	18.4	17.9	16.7	2.1
	17:30	41.0	20.4	20.3	18.5	18.0	16.7	1.9
	17:20	41.4	20.5	20.3	18.4	17.9	16.7	2.1
	17:10	40.5	20.4	20.3	18.4	18.0	16.6	2.0
	AVG	40.1						AVG 2.04
II DISCHARGE PHASE:								
END	21:00	-259.0	20.6	20.5	18.6	18.0	16.6	2.0
	20:50	-259.7	20.7	20.6	18.6	18.1	16.6	2.1
	20:40	-283.7	20.8	20.6	18.7	18.0	16.6	2.1
	20:30	-298.2	20.8	20.6	18.6	18.0	16.6	2.2
	20:20	-300.3	20.8	20.6	18.6	18.0	16.6	2.2
	20:10	-314.1	20.8	20.6	18.6	18.0	16.6	2.2
	20:00	-339.9	20.6	20.5	18.6	18.0	16.6	2.0
	19:50	-360.1	20.5	20.4	18.5	18.0	16.7	2.0
	19:40	-364.9	20.4	20.2	18.4	17.9	16.7	2.0
	19:30	-358.2	20.1	20.0	18.4	17.8	16.7	1.7
	19:20	-271.5	20.1	19.9	18.3	17.8	16.8	1.8
	19:10	-242.3	20.1	19.9	18.4	17.8	16.7	1.7
	19:00	-228.9	20.1	20.0	18.4	17.8	16.7	1.7
	18:50	-220.3	20.3	20.1	18.4	17.9	16.7	1.9
	18:40	-223.7	20.4	20.2	18.4	17.9	16.6	2.0
	18:30	-224.5	20.6	20.4	18.5	18.0	16.7	2.1
	AVG	284.3						AVG 2.0

TABLE 3

RUN #3, DAY 82, 100 WATTS NOMINAL WASTE

	TIME	WATTS	TOC CH 45	MOC CH 48	BOC CH 51	COLD PLATE CH 60	COOL IN CH 62	TEMP TOP TO BOTTOM
I OVERCHARGE PHASE								
END	15:20	100.8	22.8	22.0	17.1	16.1	12.7	5.7
	15:10	99.6	22.7	22.0	17.0	16.0	12.7	5.7
	15:00	100.9	22.7	22.0	17.0	16.0	12.6	5.7
	14:50	99.2	22.7	22.0	17.1	16.1	12.5	5.6
	14:40	99.5	22.7	21.9	17.0	16.1	12.6	5.7
	14:30	100.1	22.7	21.9	17.0	16.1	12.8	5.7
	AVG	100					AVG	5.68
II DISCHARGE PHASE:								
	18:00	589.1	23.9	23.1	17.5	16.5	12.6	6.4
	17:50	588.9	23.8	22.9	17.3	16.4	12.5	6.5
	17:40	590.8	23.6	22.8	17.3	16.4	12.5	6.3
	17:30	5[illegible].4	23.5	22.7	17.2	16.4	12.3	6.3
	17:20	588.4	23.4	22.6	17.3	16.3	12.6	6.1
	17:10	588.7	23.2	22.5	17.2	16.3	12.7	6.0
	17:00	589.1	23.2	22.4	17.1	16.2	12.6	6.1
	16:50	588.0	23.2	22.4	17.2	16.2	12.6	6.0
	16:40	590.2	23.2	22.4	17.2	16.2	12.4	6.0
	16:30	605.5	23.2	22.5	17.2	16.2	12.5	6.0
	16:20	624.2	23.3	22.4	17.2	16.2	12.7	6.1
	16:10	634.3	23.3	22.4	17.1	16.1	12.6	6.2
	16:00	643.3	23.2	22.3	17.1	16.1	12.5	6.1
	15:50	644.1	23.2	22.3	17.2	16.2	12.5	6.0
	15:40	650.4	23.1	22.2	17.2	16.2	12.5	5.9
	15:30	650.1	22.7	22.0	17.1	16.1	12.7	5.6
	AVG	609.7					AVG	6.1

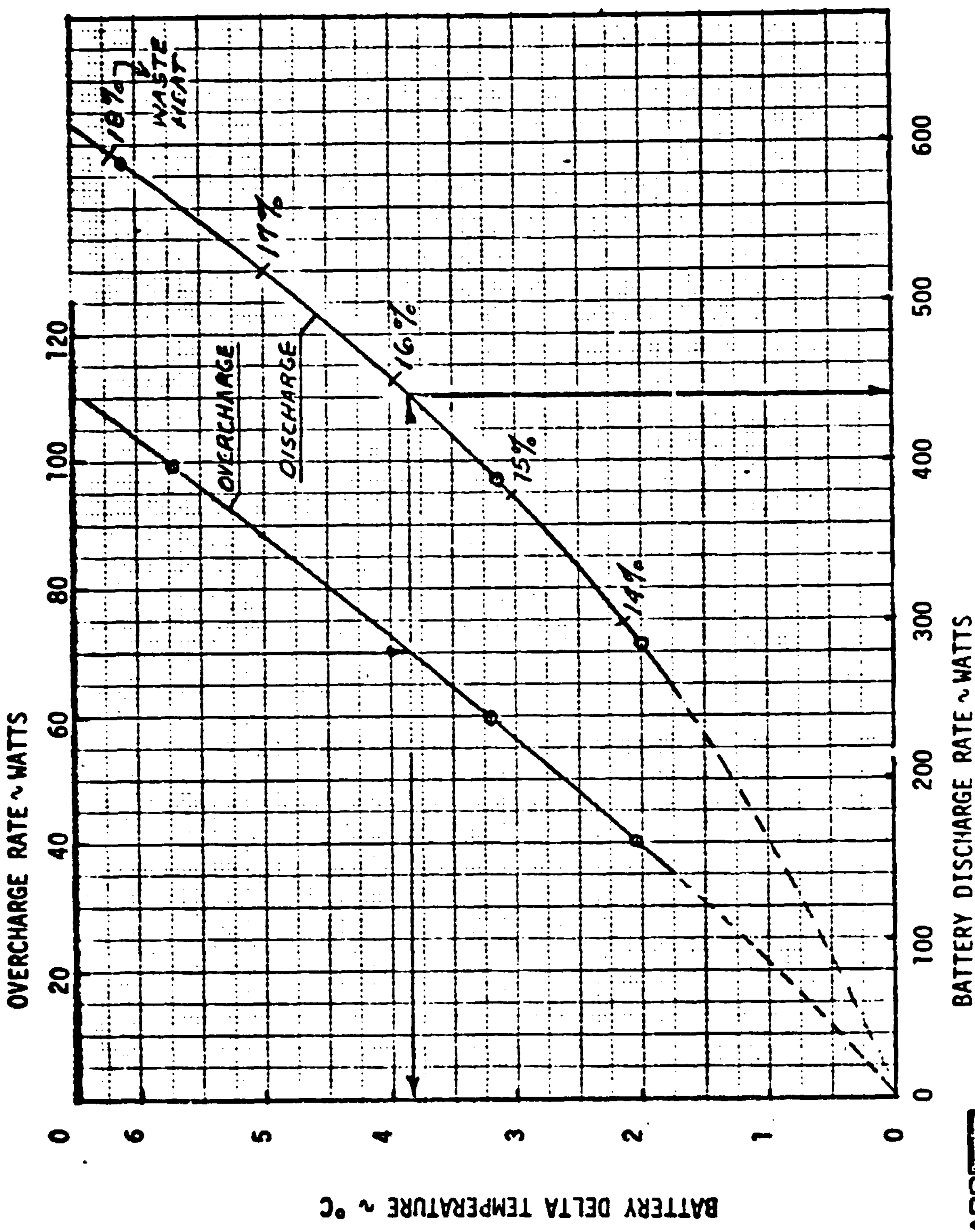
TYPICAL TEMPERATURE DISTRIBUTIONS DURING BATTERY
CHARGE & DISCHARGE CONDITIONS
(TEMPERATURES IN °C)

LOCATION		FIN/TC	CHARGE	CHARGE PHASE (END) DAY 80 18:10	DISCHG PHASE (END) DAY 80 21:05	CHARGE PHASE (END) DAY 81 14:25	DISCHG PHASE (END) DAY 81 16:50	CHARGE PHASE (END) DAY 82 15:20	DISCHG PHASE DAY 82 17:20	
TOP OF CELLS		6 - 1	44	19.7	19.9	20.0	20.0	21.7	22.4	
	℄	6 - 2	45	20.5	20.6	20.9	20.8	22.8	23.4	℄
		6 - 4	46	20.6	20.8	21.0	21.0	22.9	23.6	
	℄	1 - 2	40	19.8	20.0	20.3	20.2	21.9	22.5	℄
		1 - 4	41	19.9	20.1	20.2	20.4	22.1	22.7	
	℄	10 - 2	53	19.8	19.9	19.9	19.9	21.2	21.6	℄
		10 - 4	54	19.7	19.8	19.7	19.8	21.8	21.5	
MID CELL	℄	---	32	20.13	20.35	20.55	20.60	22.55	23.22	℄
	℄	---	33	20.12	20.32	20.52	20.59	22.54	23.22	℄
	℄	---	34	20.09	20.30	20.50	20.57	22.50	23.19	℄
		6 - 5	47	19.4	19.6	19.6	19.5	20.8	21.3	
	℄	6 - 6	48	20.3	20.5	20.4	20.5	22.0	22.6	℄
		6 - 8	49	19.9	20.2	20.0	20.1	21.2	21.9	
BOTTOM OF CELLS		6 - 9	50	17.6	17.7	16.6	16.6	15.7	16.0	
	℄	6 - 10	51	18.5	18.6	17.5	17.7	17.1	17.3	℄
		6 - 12	52	19.1	19.8	18.6	18.8	18.8	19.4	
	℄	1 - 10	42	18.6	18.7	17.9	18.0	17.8	18.1	℄
		1 - 12	3	19.1	19.3	18.8	18.9	19.3	19.9	
	℄	10 - 10	55	18.0	18.0	16.7	16.8	15.6	15.7	℄
		10 - 12	56	18.4	18.6	17.7	17.8	17.2	17.7	
COLD-PLATE			60	17.9		16.9	17.0	16.1	16.3	
			61	18.0		16.9	17.0	16.0	16.3	
COOL IN			62	16.6		14.9	15.0	12.7	12.6	
COOL OUT			63	17.0		15.4	15.5	13.6	13.5	

FIGURE 1

-- 50 AH BATTERY THERMAL QUAL TESTS --

BATTERY TOP-TO-BOTTOM TEMPERATURES VS POWER RATES



MCDONNELL DOUGLAS CORPORATION

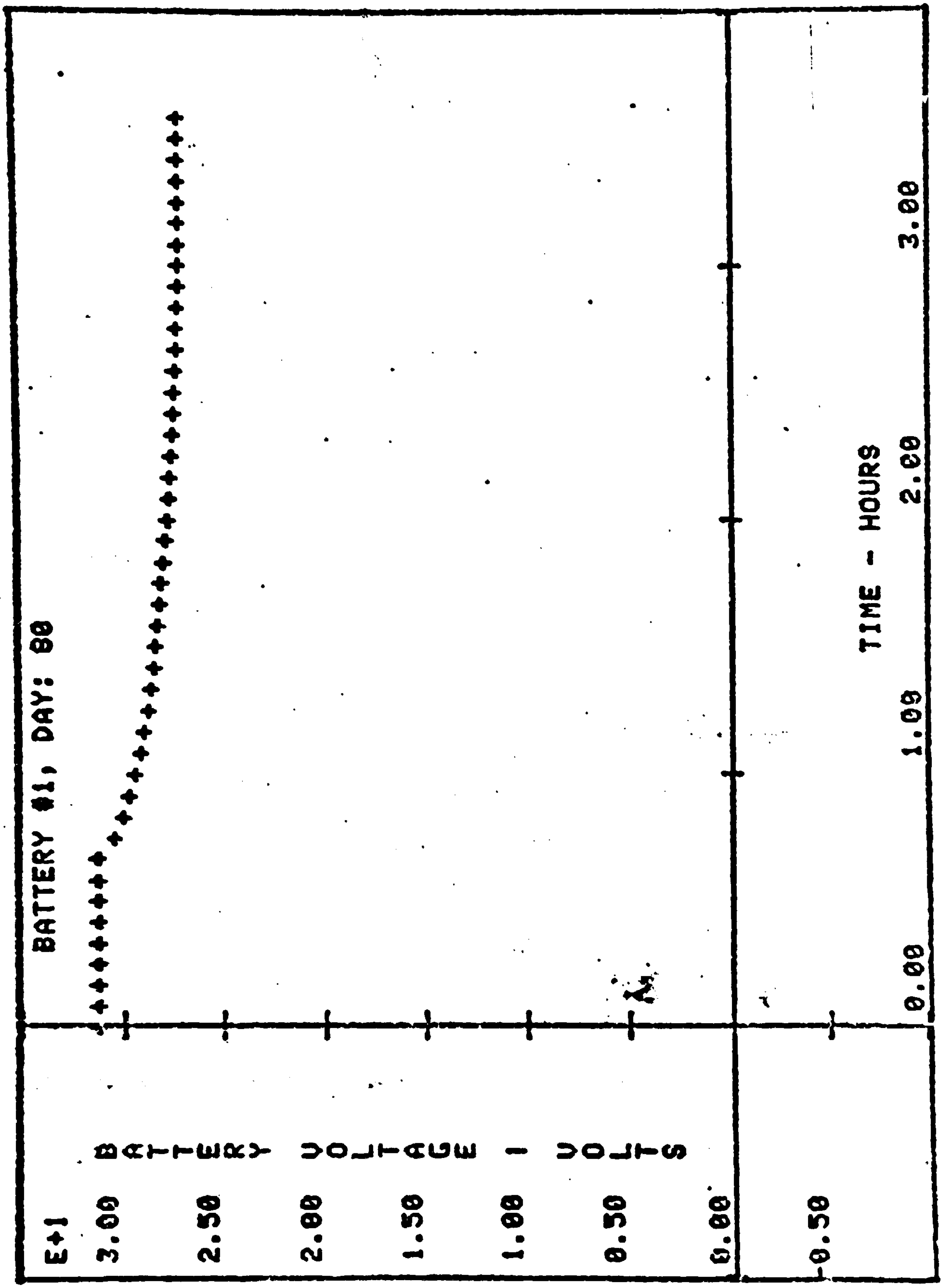
STANDARD MODULAR POWER SUBSYSTEM

APPENDIX A

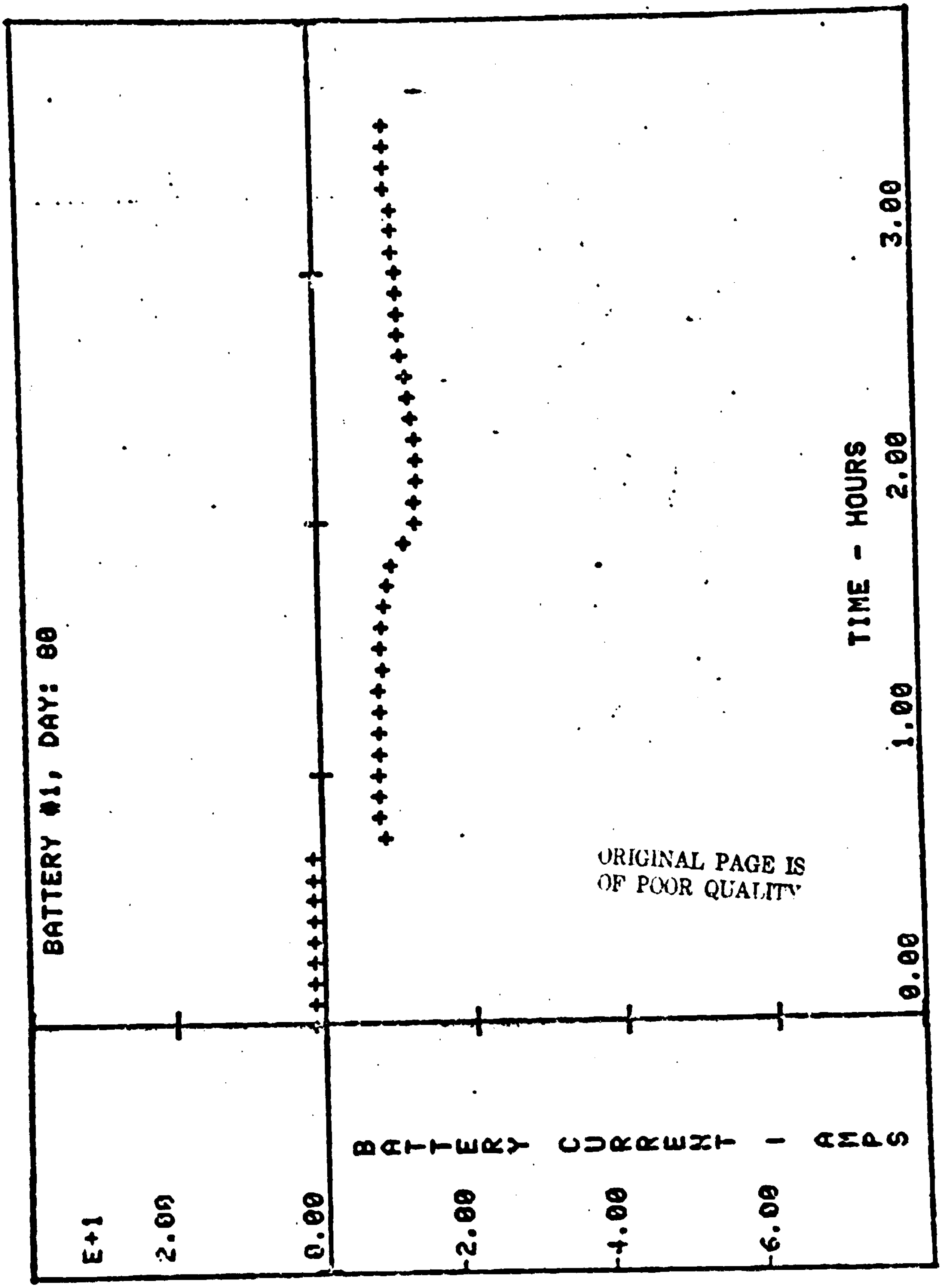
50 A.H. BATTERY

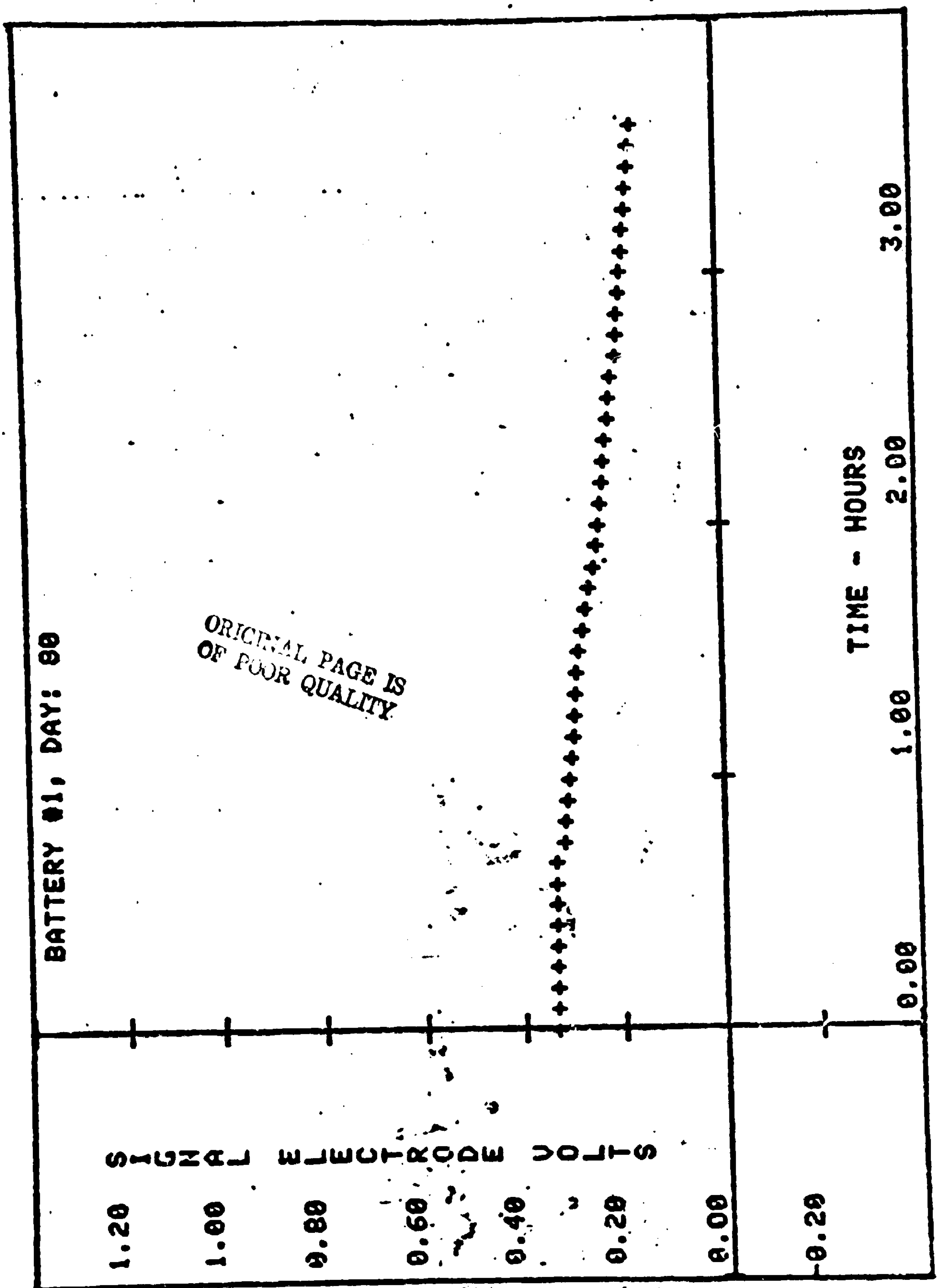
QUALIFICATION TEST

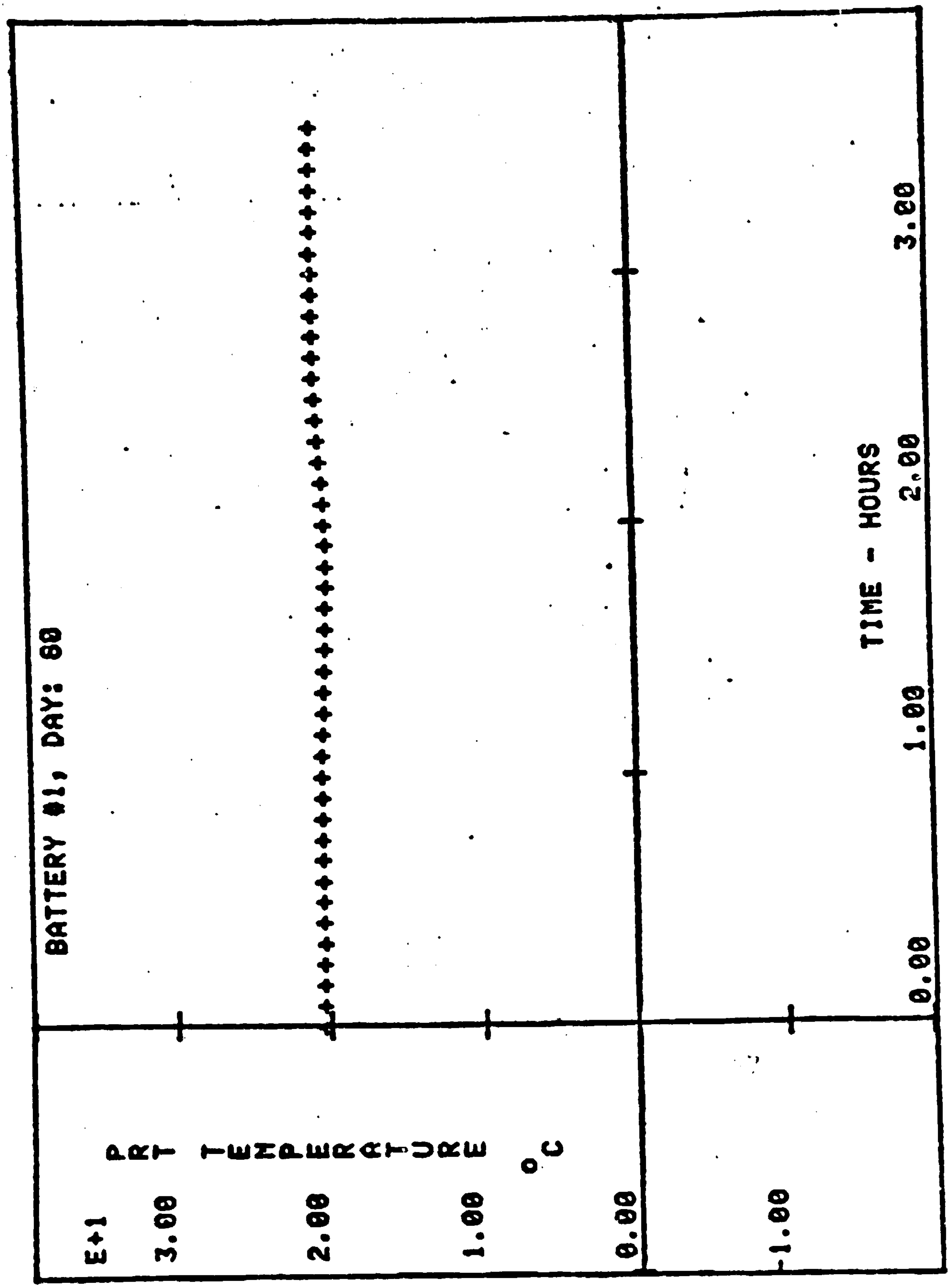
DATA PLOTS

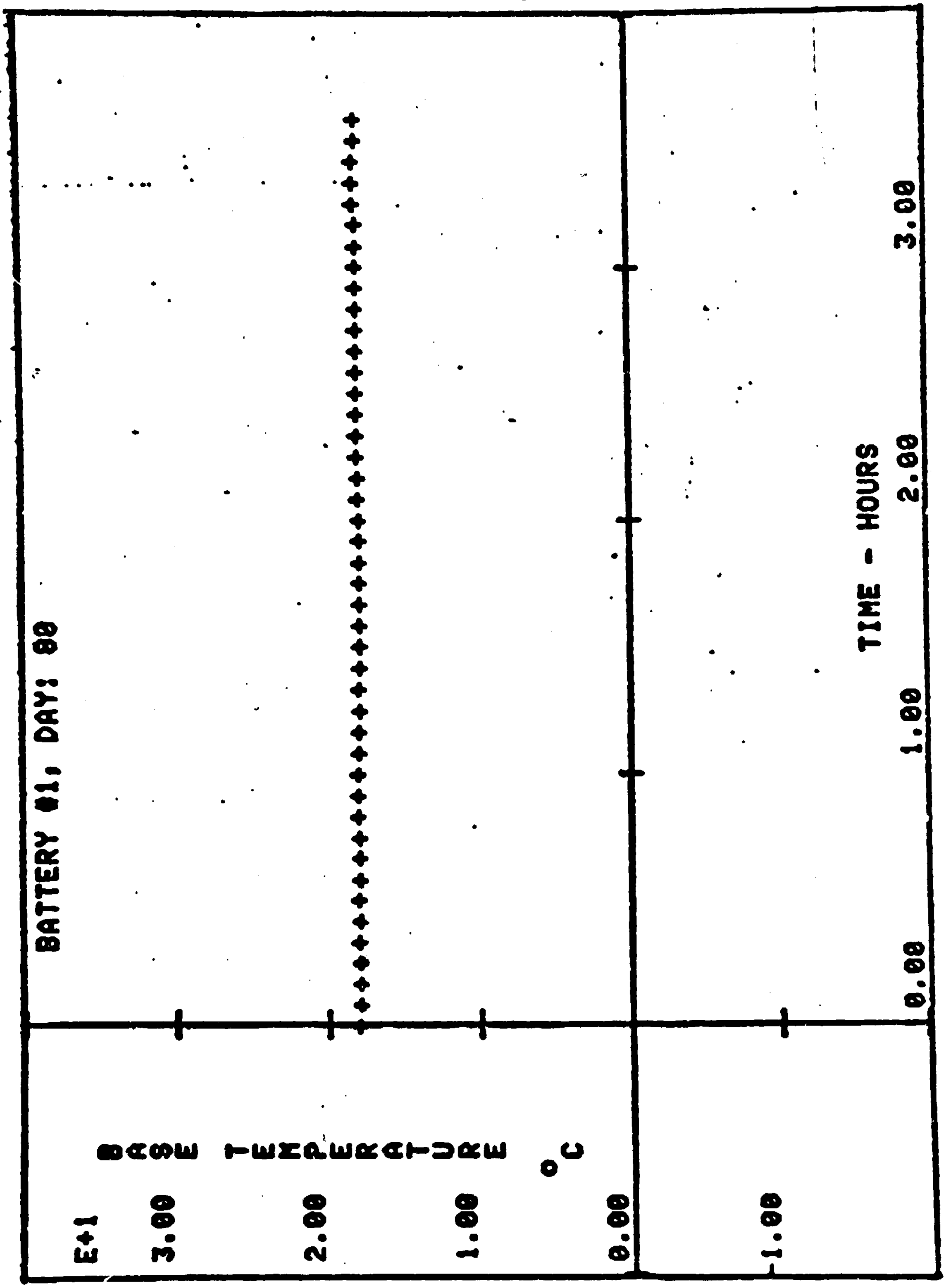


BATTERY #1, DAY: 80
BATTERY VOLTAGE - VOLTS
E+1
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
TIME - HOURS
0.00
1.00
2.00
3.00

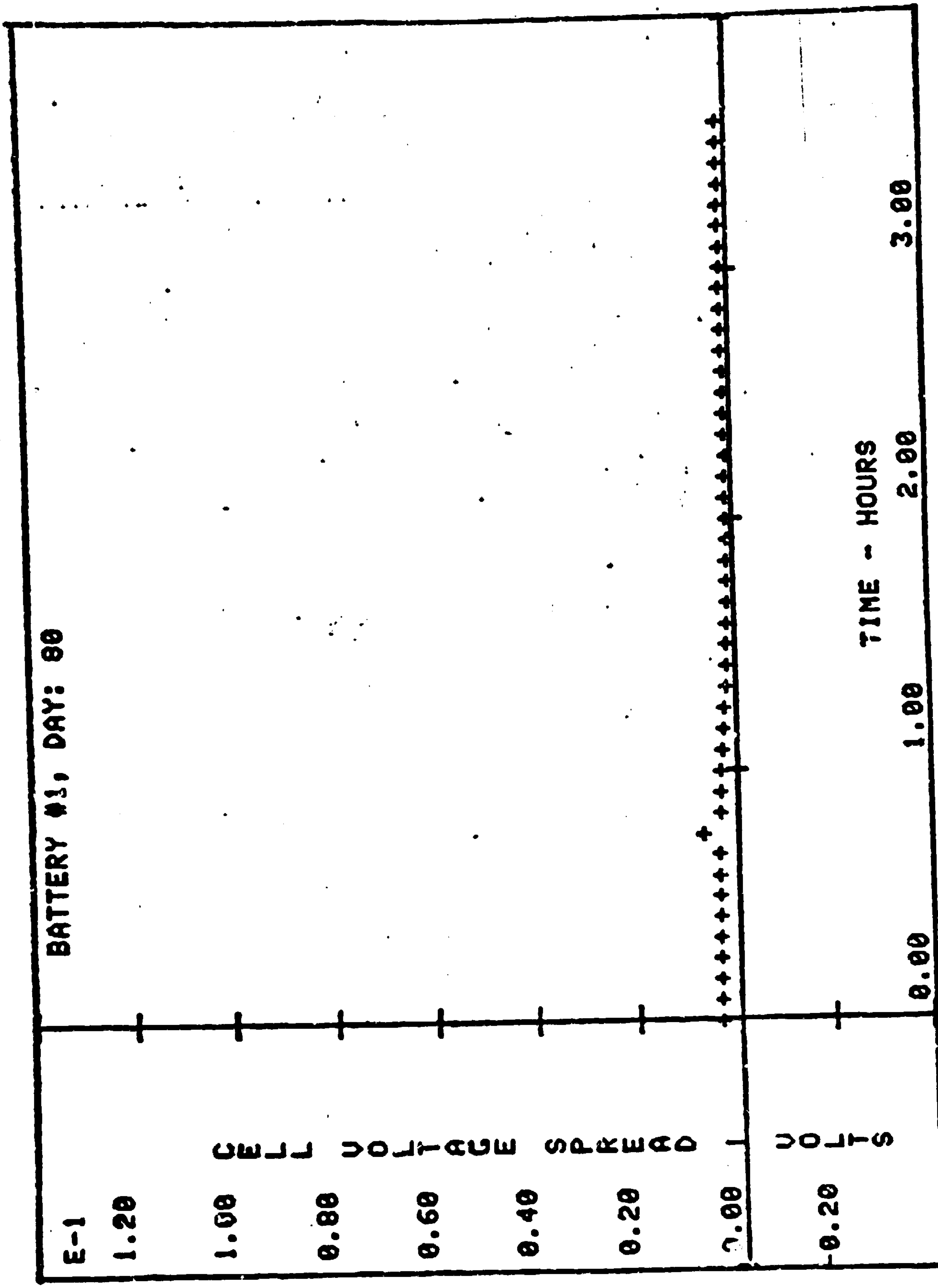

BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
BATTERY CURRENT - AMPS
E+1
2.00
0.00
-2.00
-4.00
-6.00

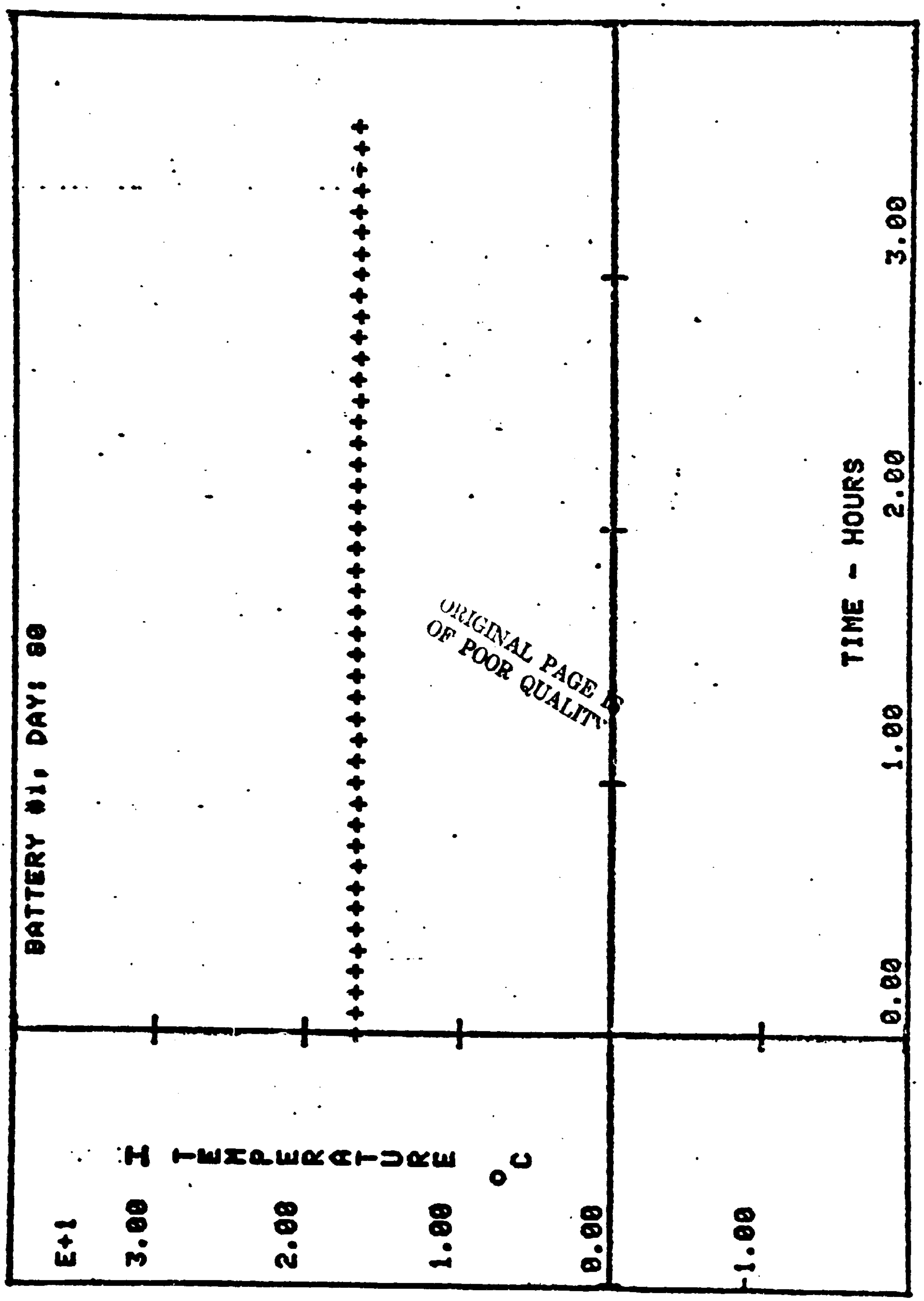

BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
SIGNAL ELECTRODE VOLTS
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20

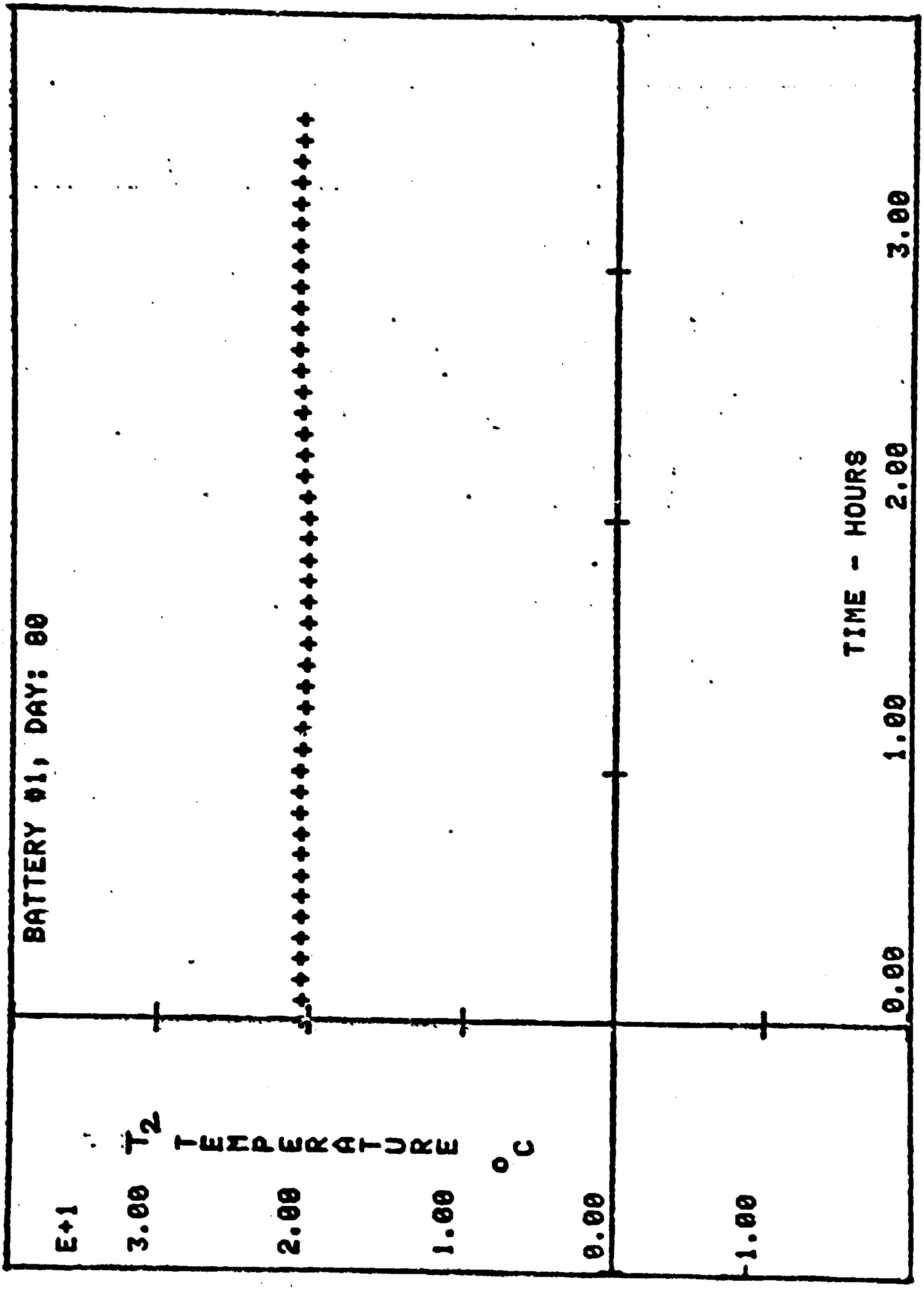

BATTERY #1, DAY: 80
PRT TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00
0.00
1.00
2.00
3.00
TIME - HOURS

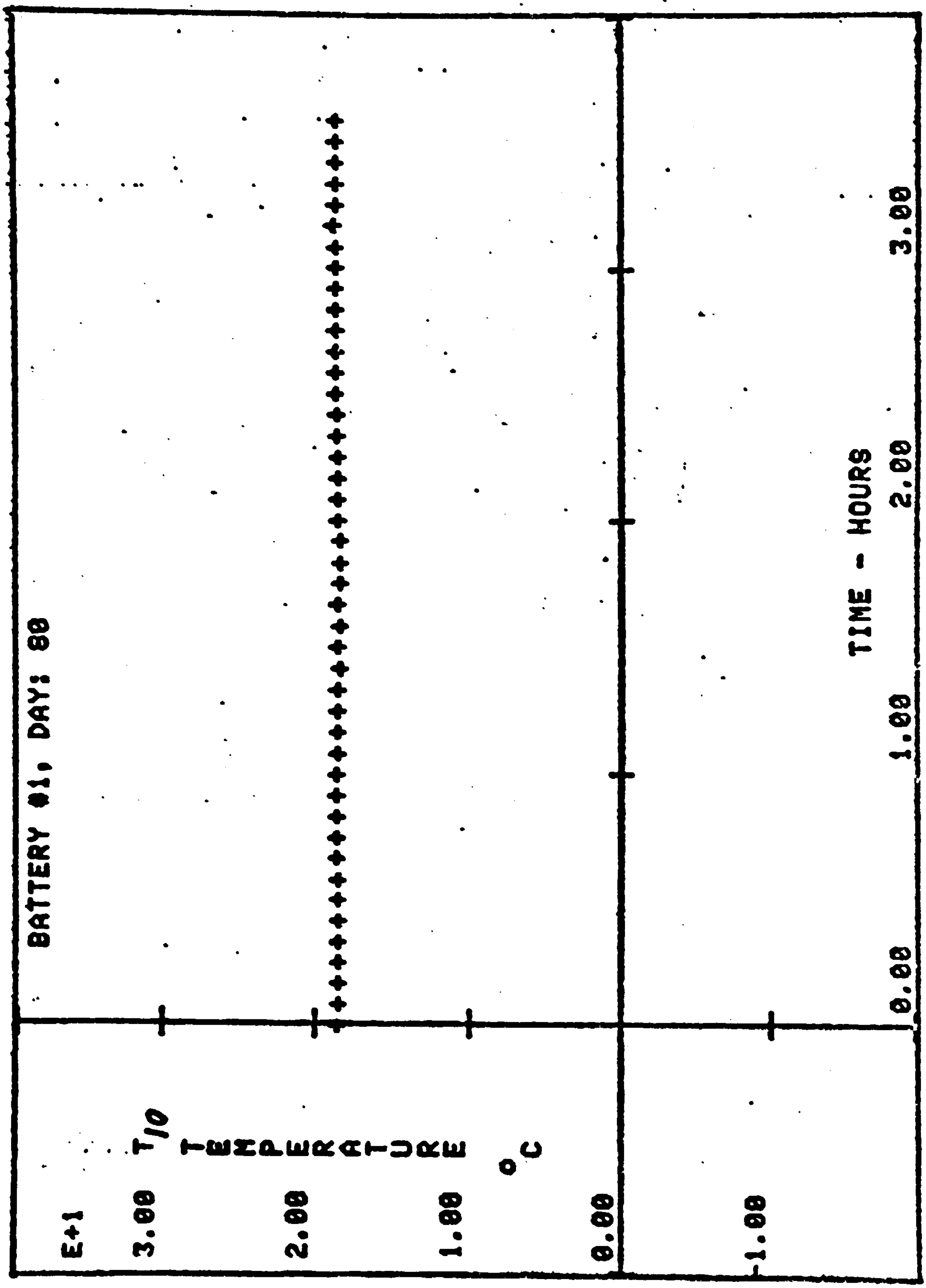


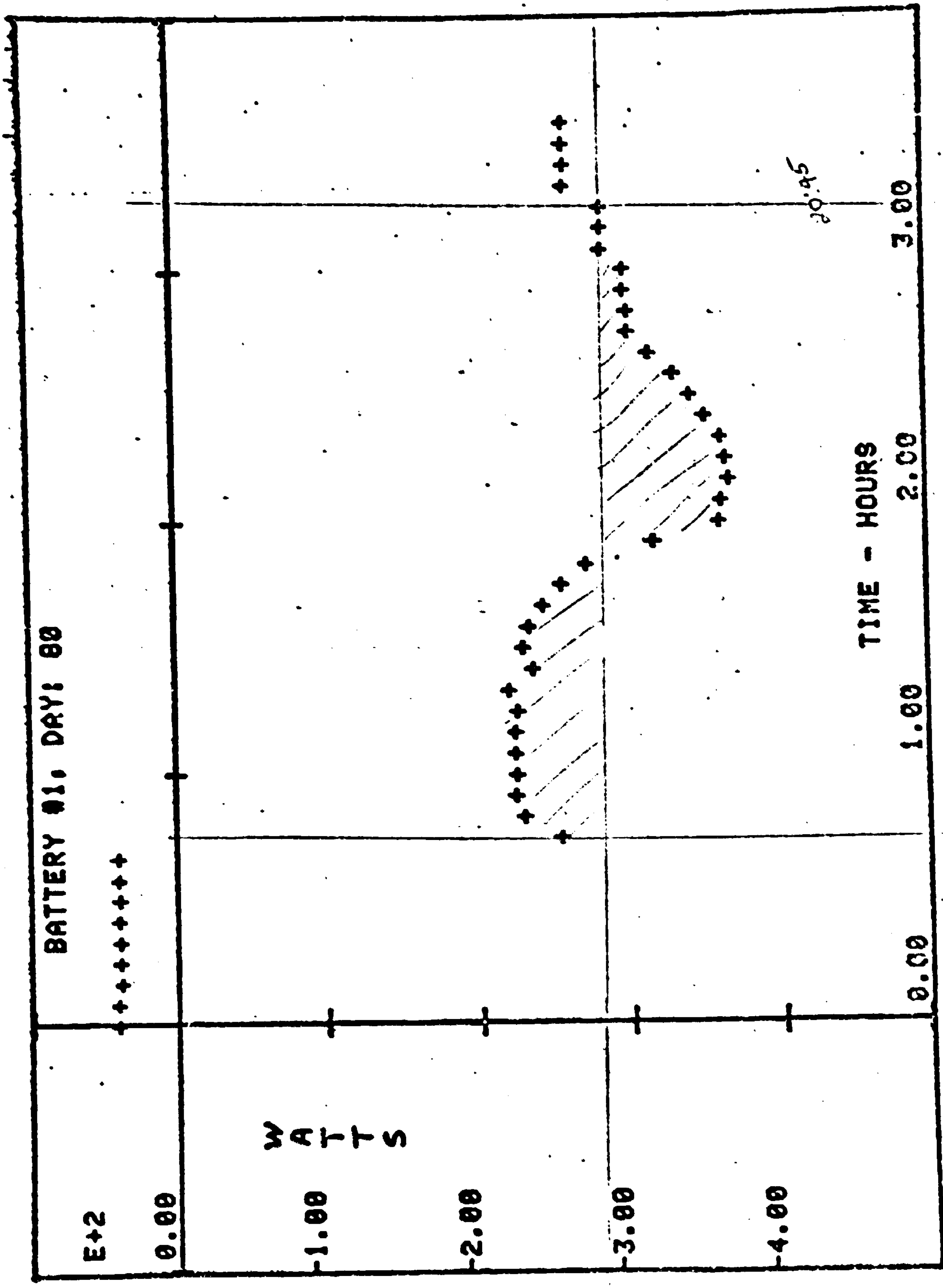
BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
BASE TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00

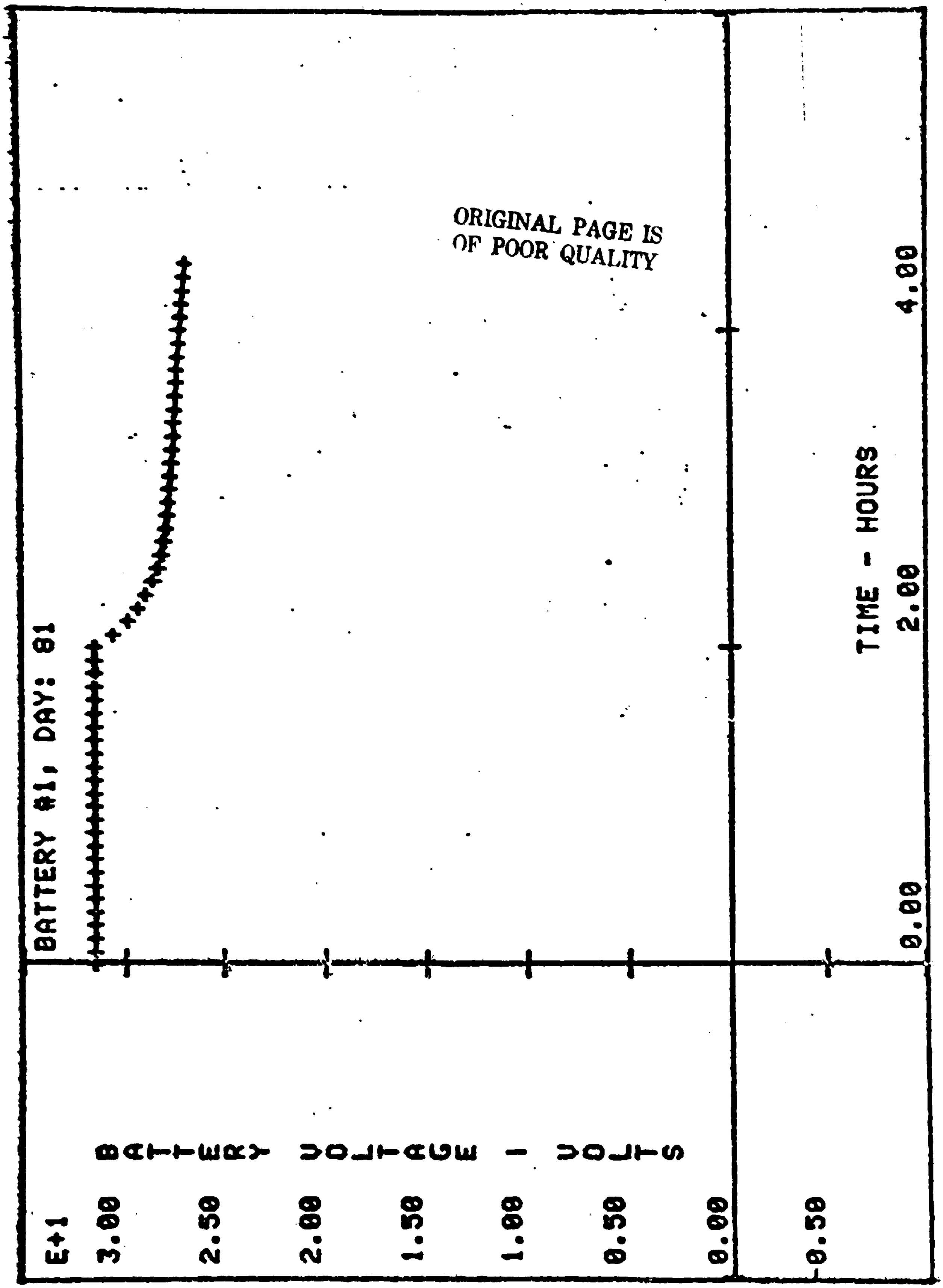

BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
CELL VOLTAGE SPREAD - VOLTS
E-1
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20

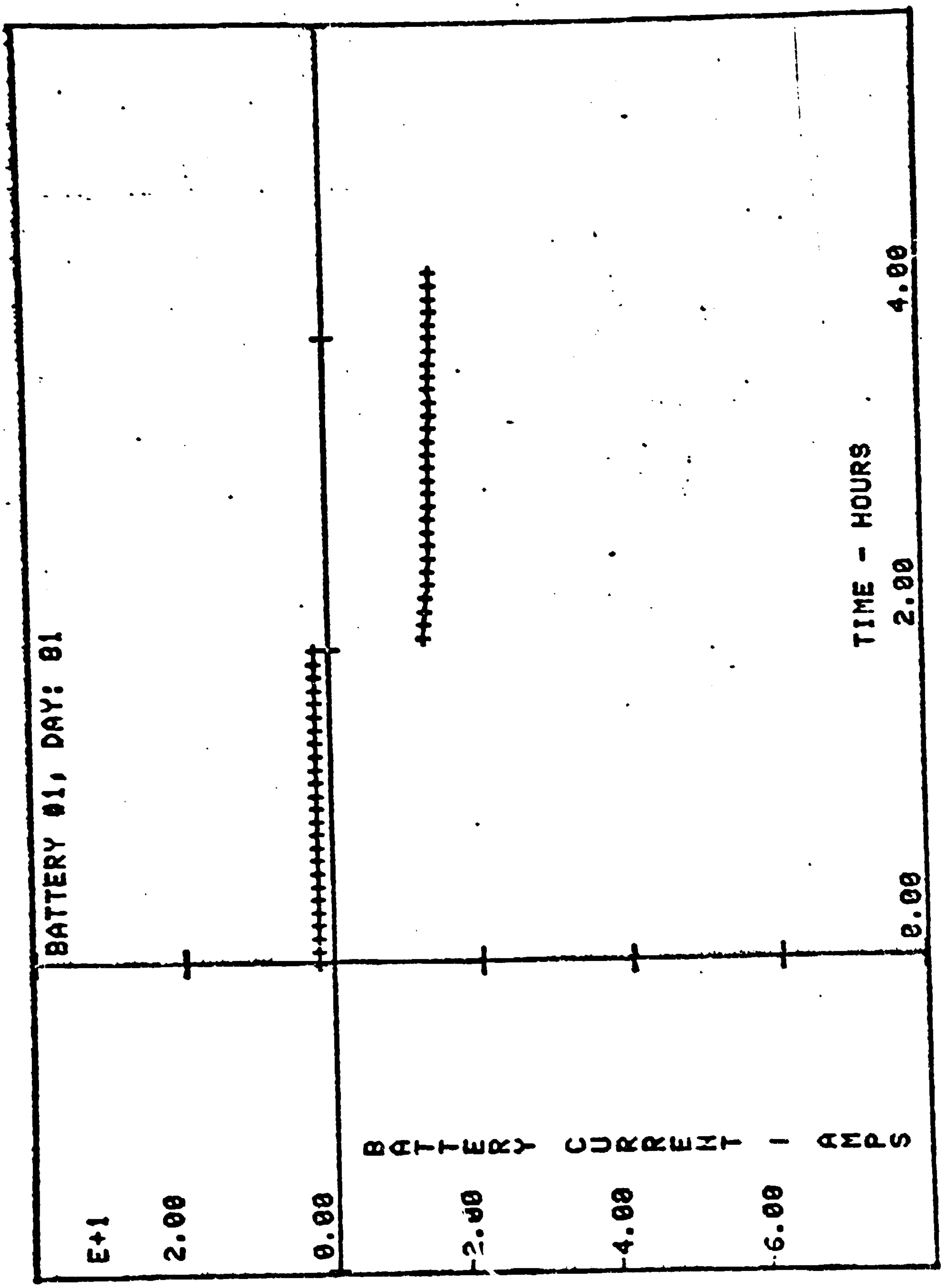

BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00
ORIGINAL PAGE IS
OF POOR QUALITY


BATTERY #1, DAY: 00
T2 TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00
TIME - HOURS
0.00
1.00
2.00
3.00

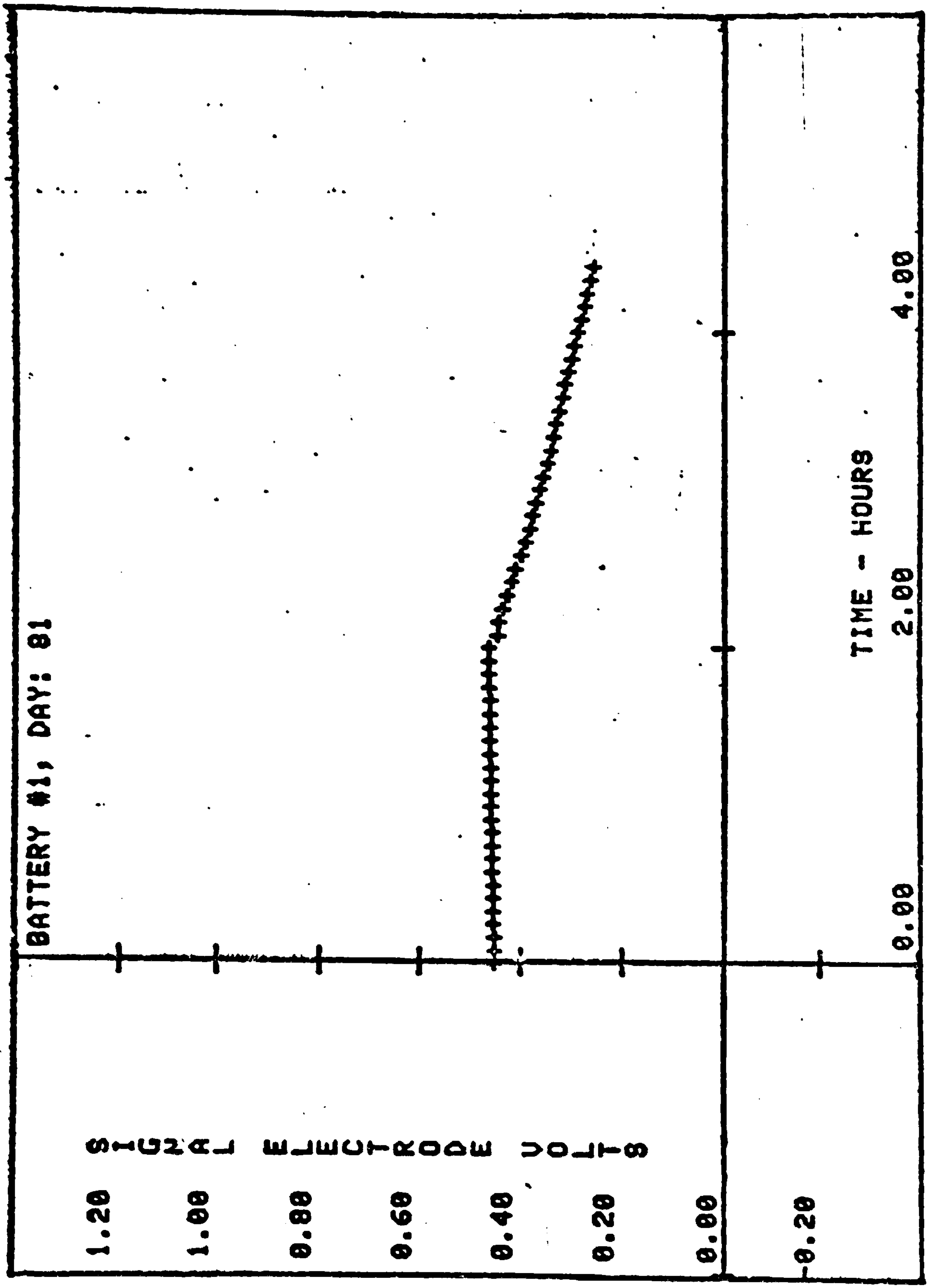

BATTERY #1, DAY: 80
TIME - HOURS
0.00
1.00
2.00
3.00
TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00

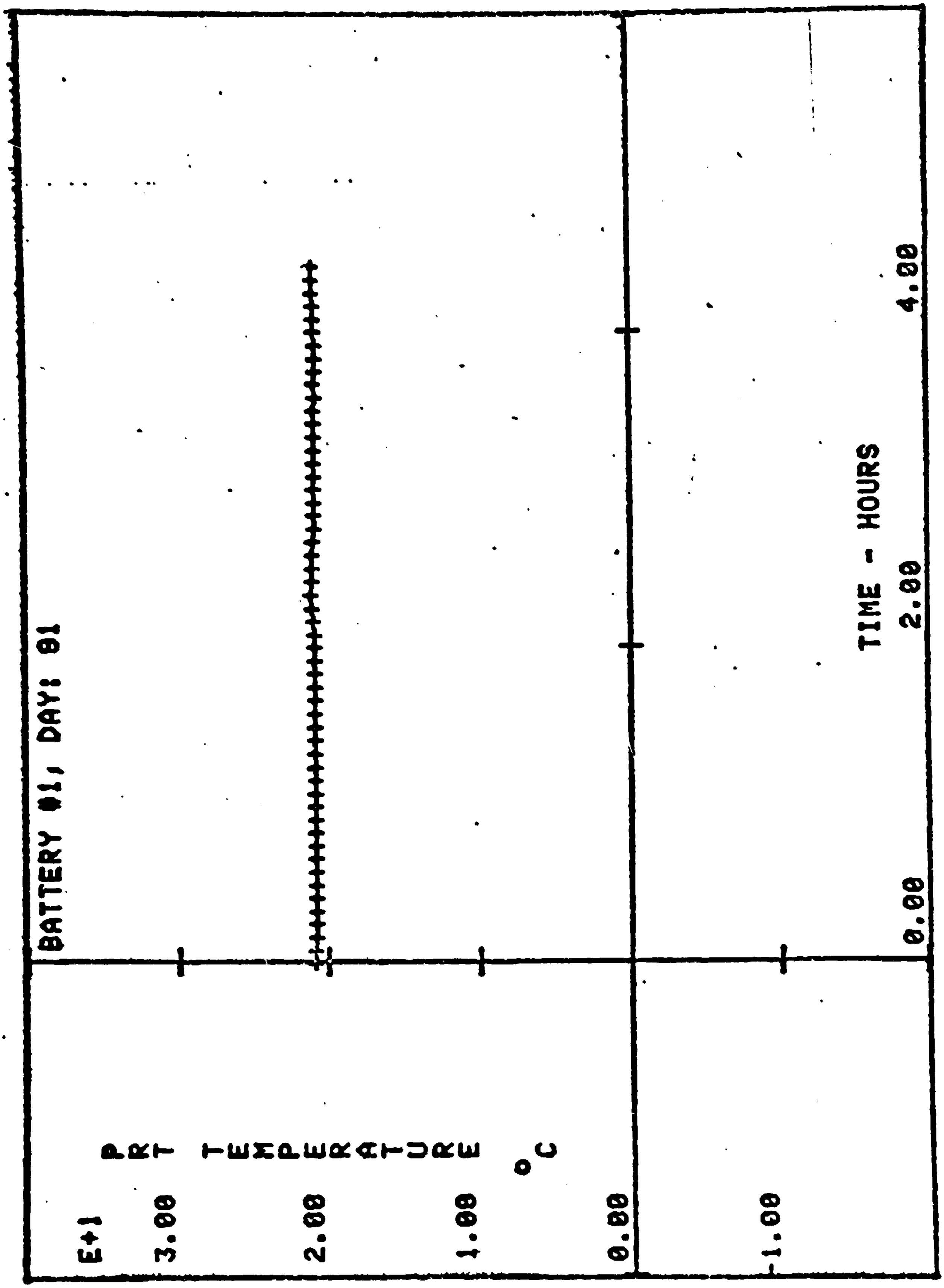

BATTERY #1, DAY: 80
E+2
0.00
-1.00
-2.00
-3.00
-4.00
WATTS
TIME - HOURS
0.00
1.00
2.00
3.00


BATTERY #1, DAY: 81
BATTERY VOLTAGE - VOLTS
E+1
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50
TIME - HOURS
0.00
2.00
4.00

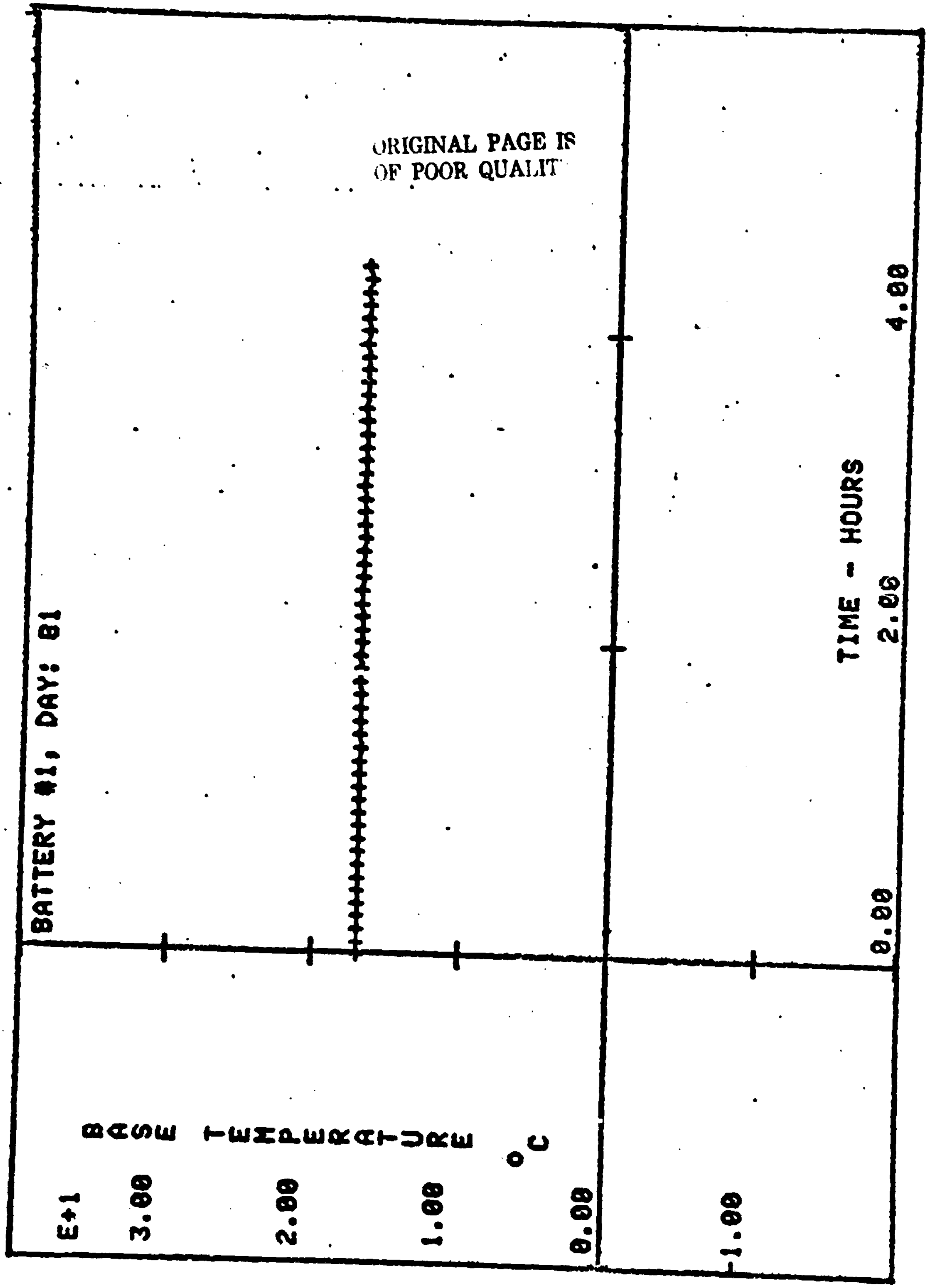


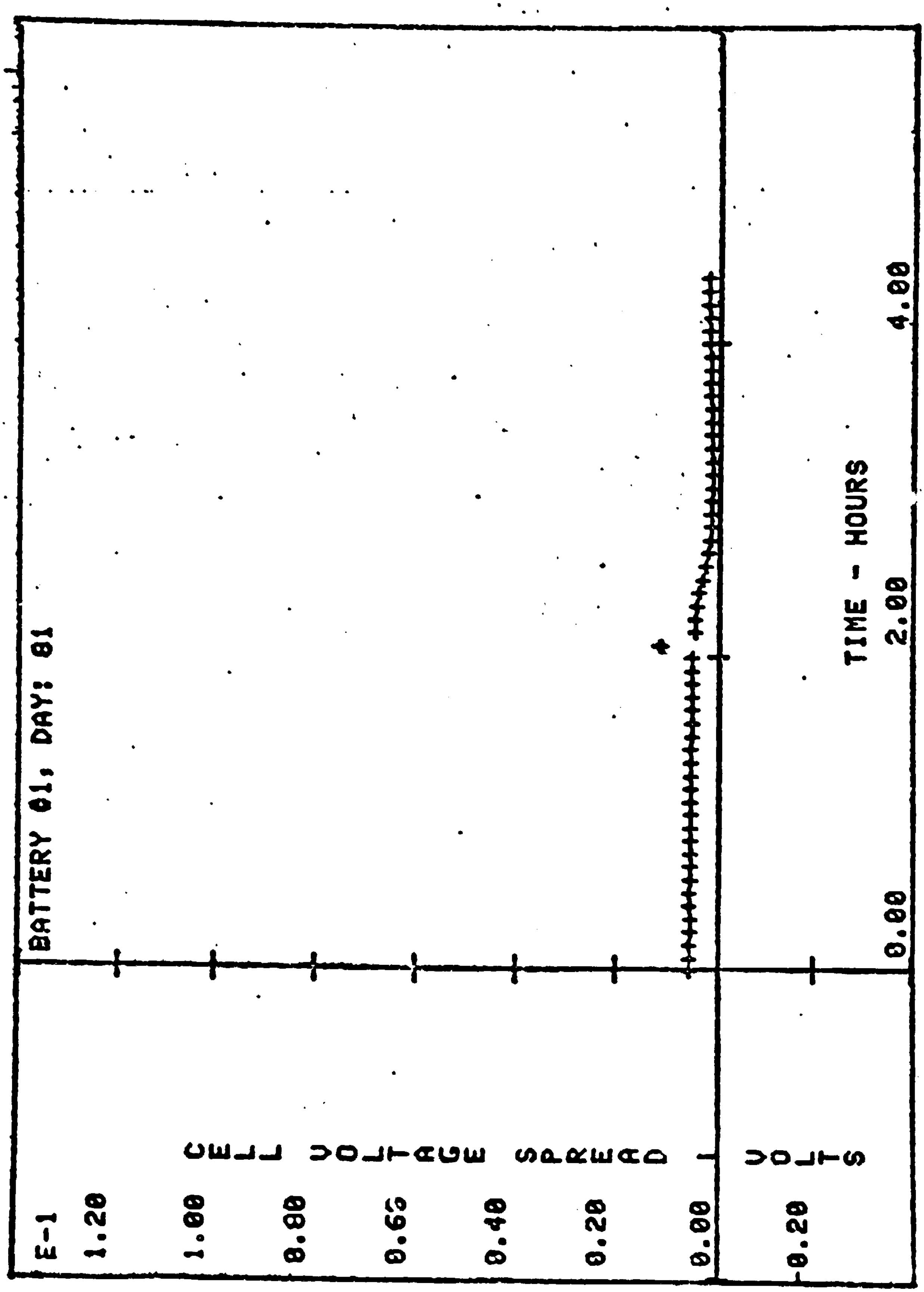
BATTERY 01, DAY: 81
TIME - HOURS
0.00
2.00
4.00
BATTERY CURRENT - AMPS
E+1
2.00
0.00
-2.00
-4.00
-6.00

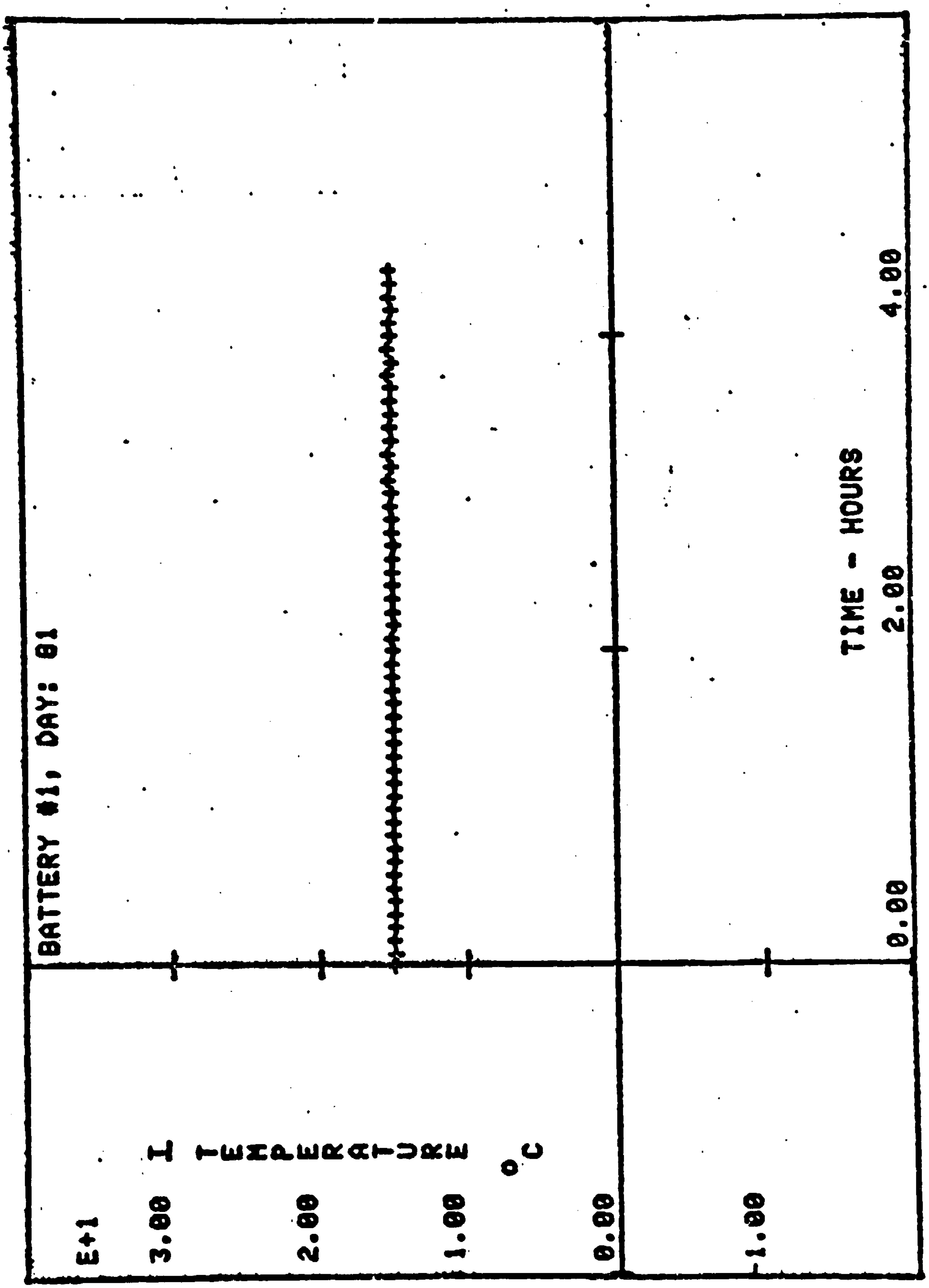

BATTERY #1, DAY: 81
TIME - HOURS
0.00
2.00
4.00
SIGNAL ELECTRODE VOLTS
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20

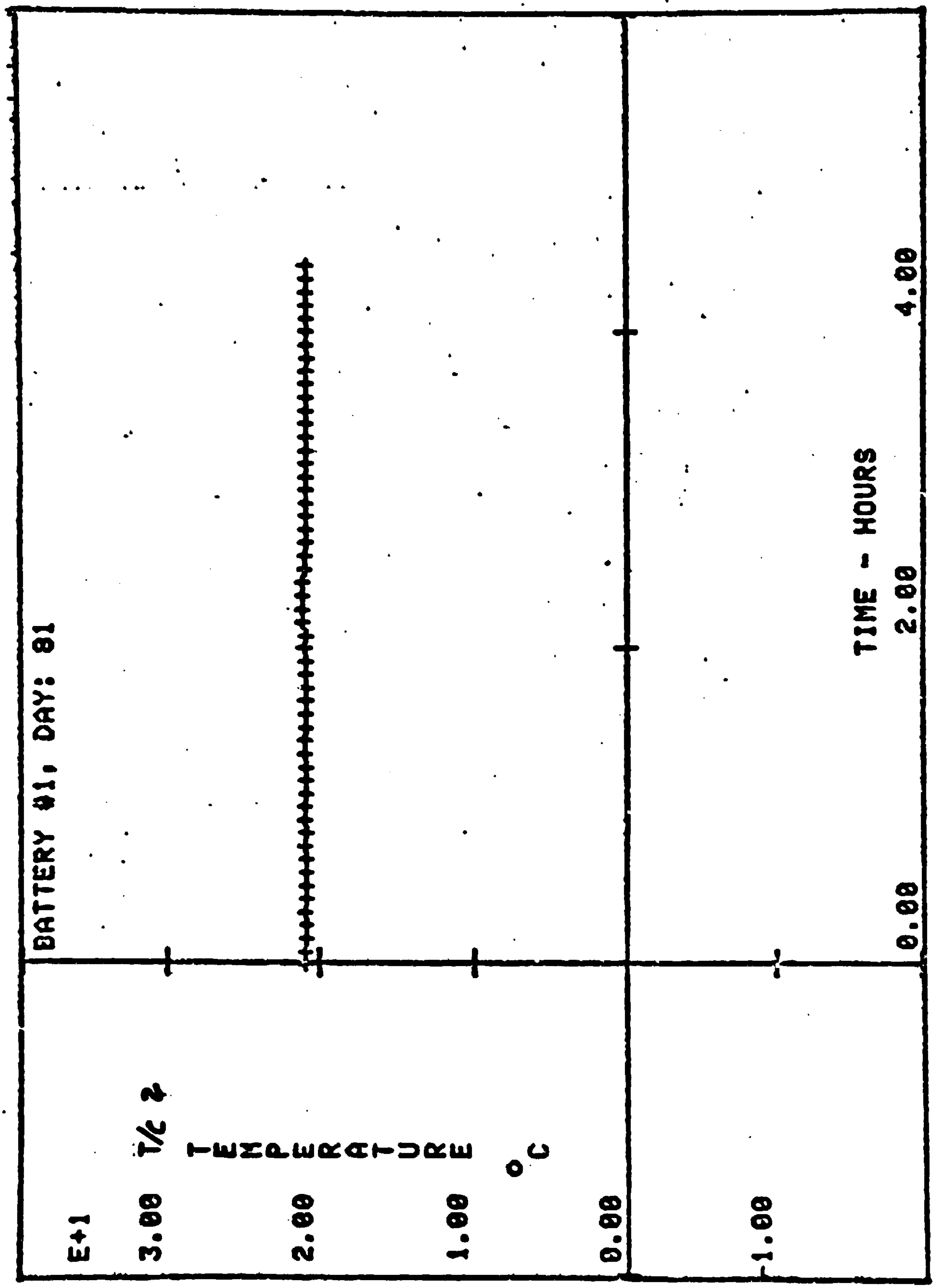

BATTERY #1, DAY: 81
PRT TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00
0.00
2.00
4.00
TIME - HOURS

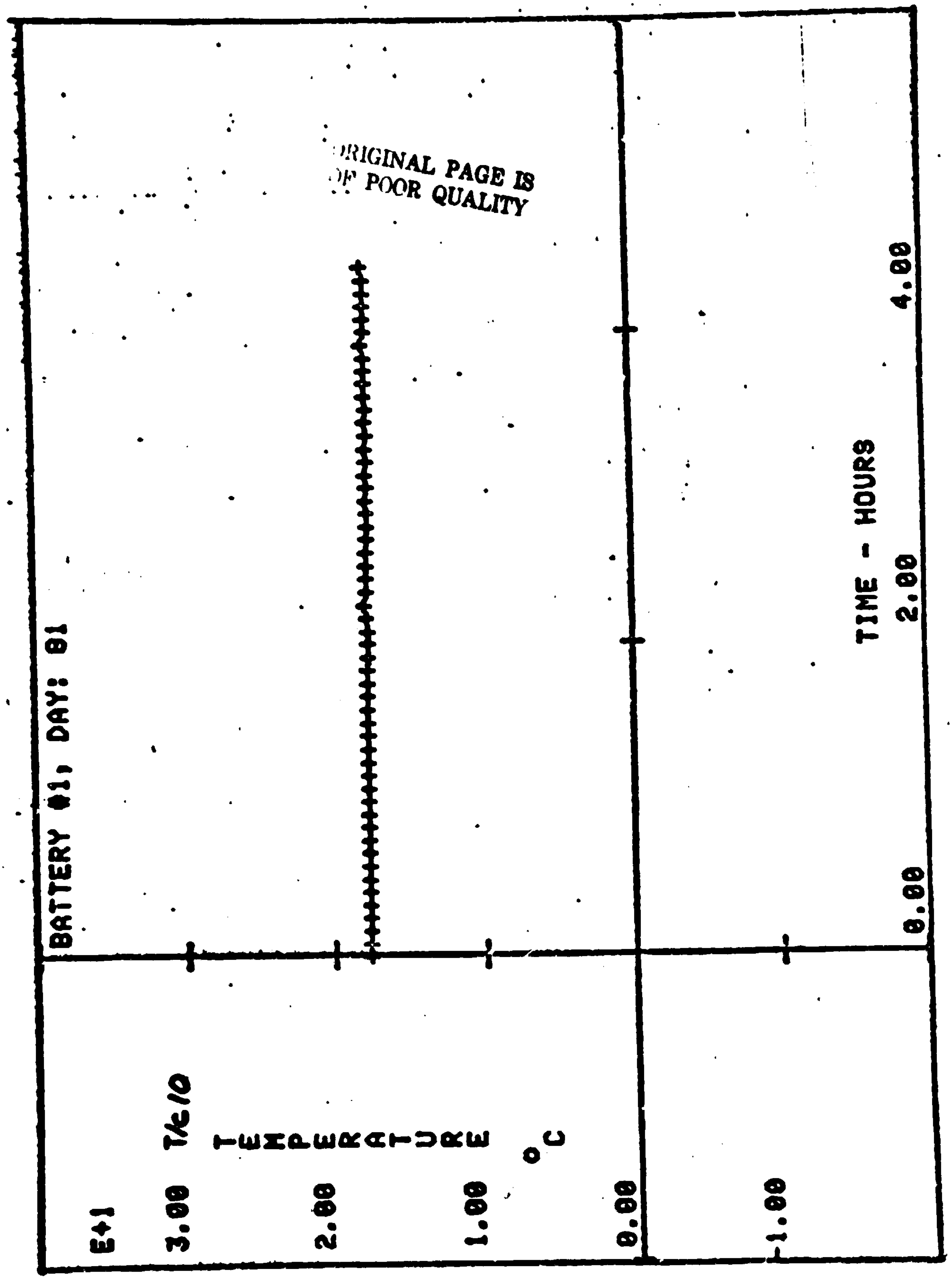
ORIGINAL PAGE IS
OF POOR QUALITY




BATTERY 01, DAY: 81
CELL VOLTAGE SPREAD - VOLTS
E-1
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
TIME - HOURS
0.00
2.00
4.00


BATTERY #1, DAY: 01
TIME - HOURS
0.00
2.00
4.00
TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00


BATTERY #1, DAY: 81
TIME - HOURS
0.00
2.00
4.00
E+1
3.00
2.00
1.00
0.00
-1.00
T/C 2
TEMPERATURE
°C


ORIGINAL PAGE IS
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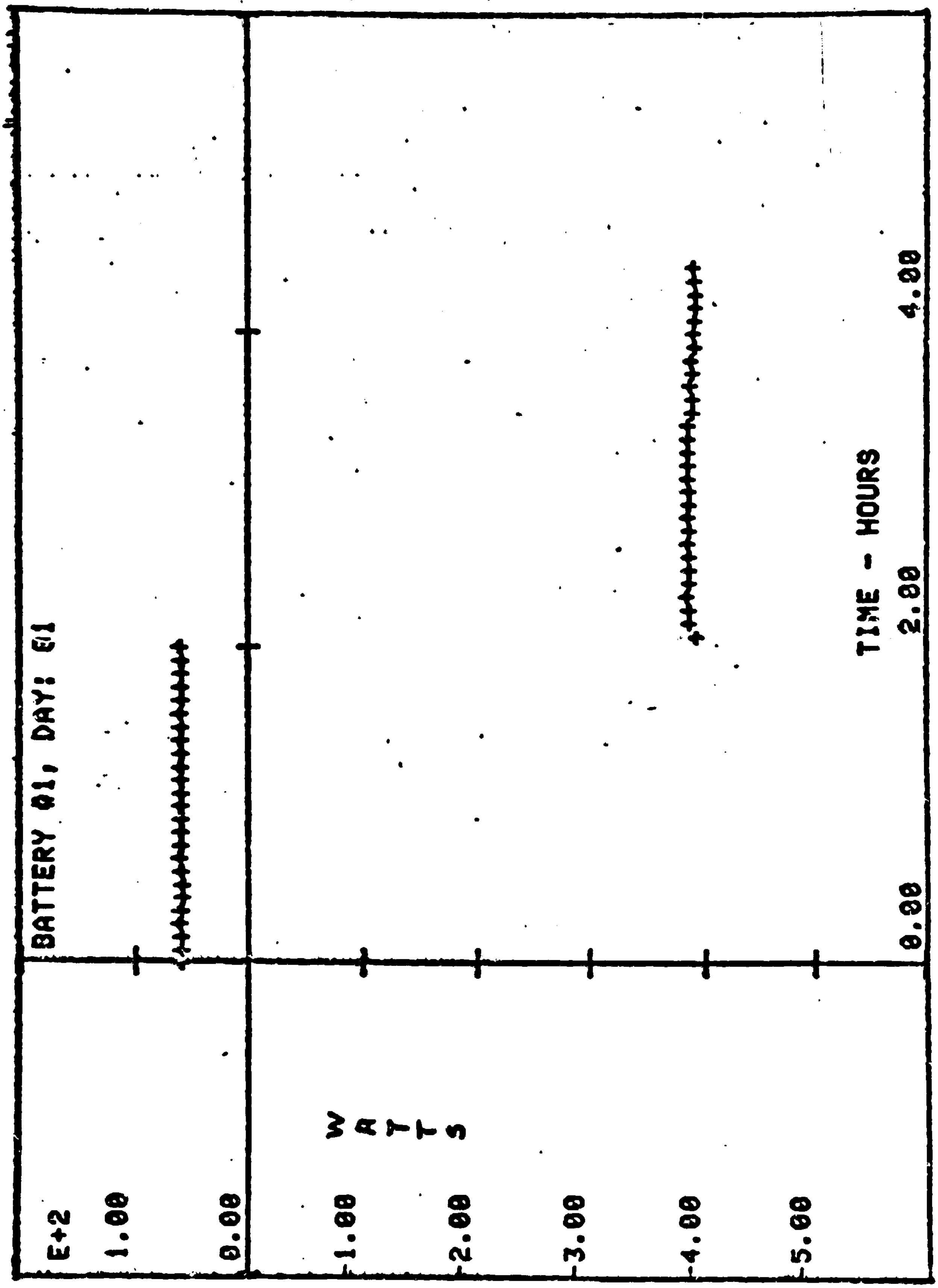
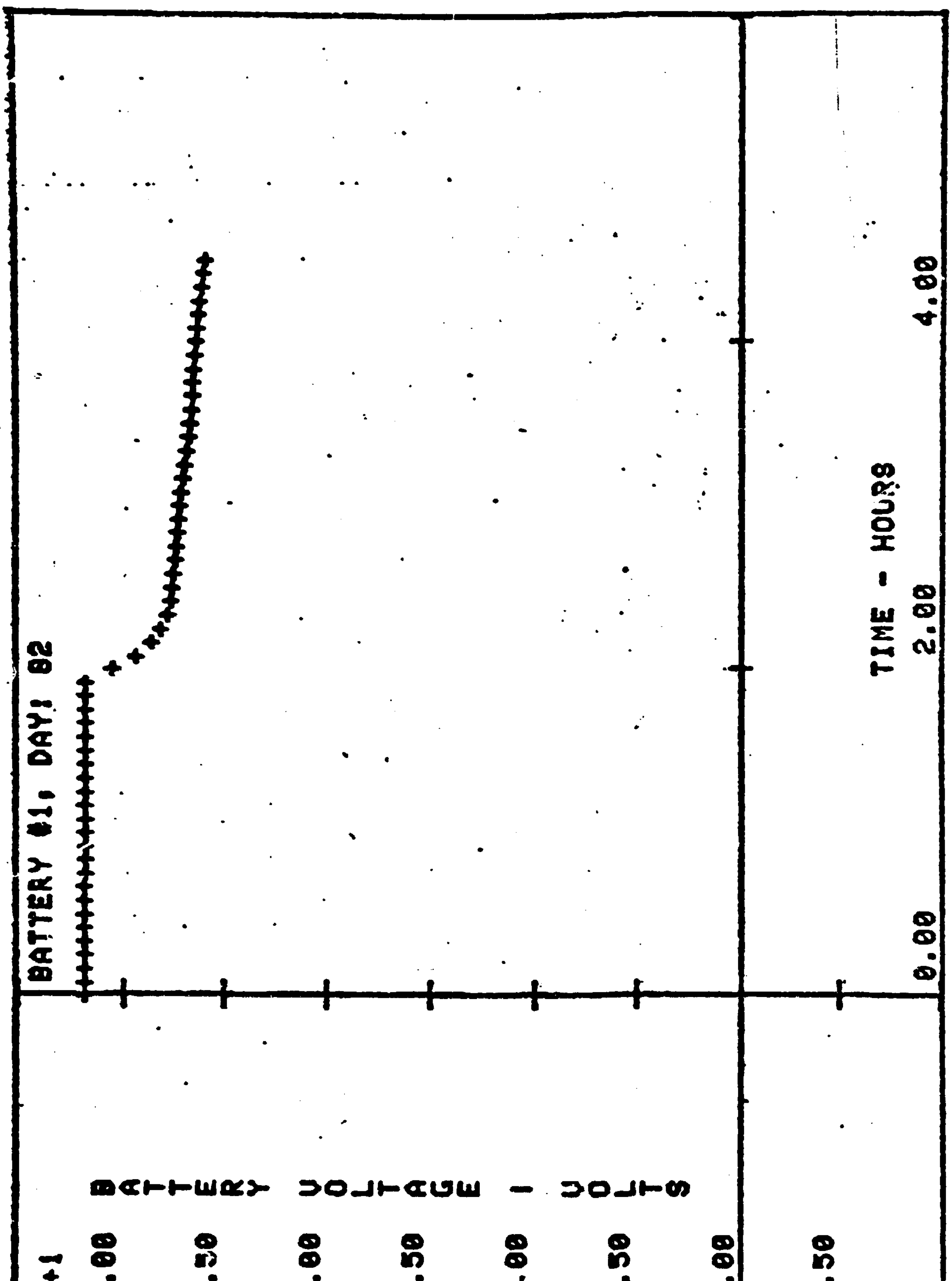
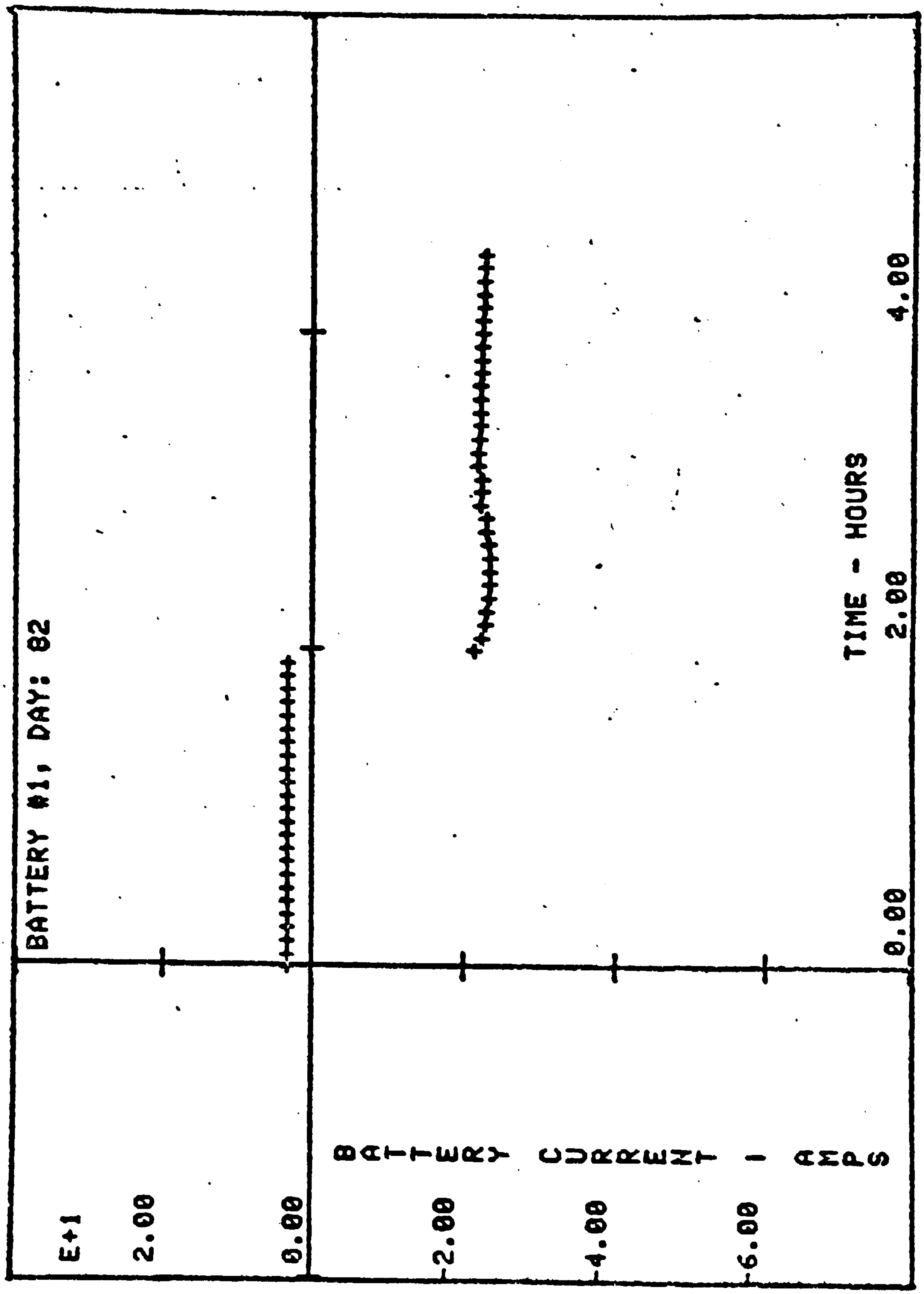
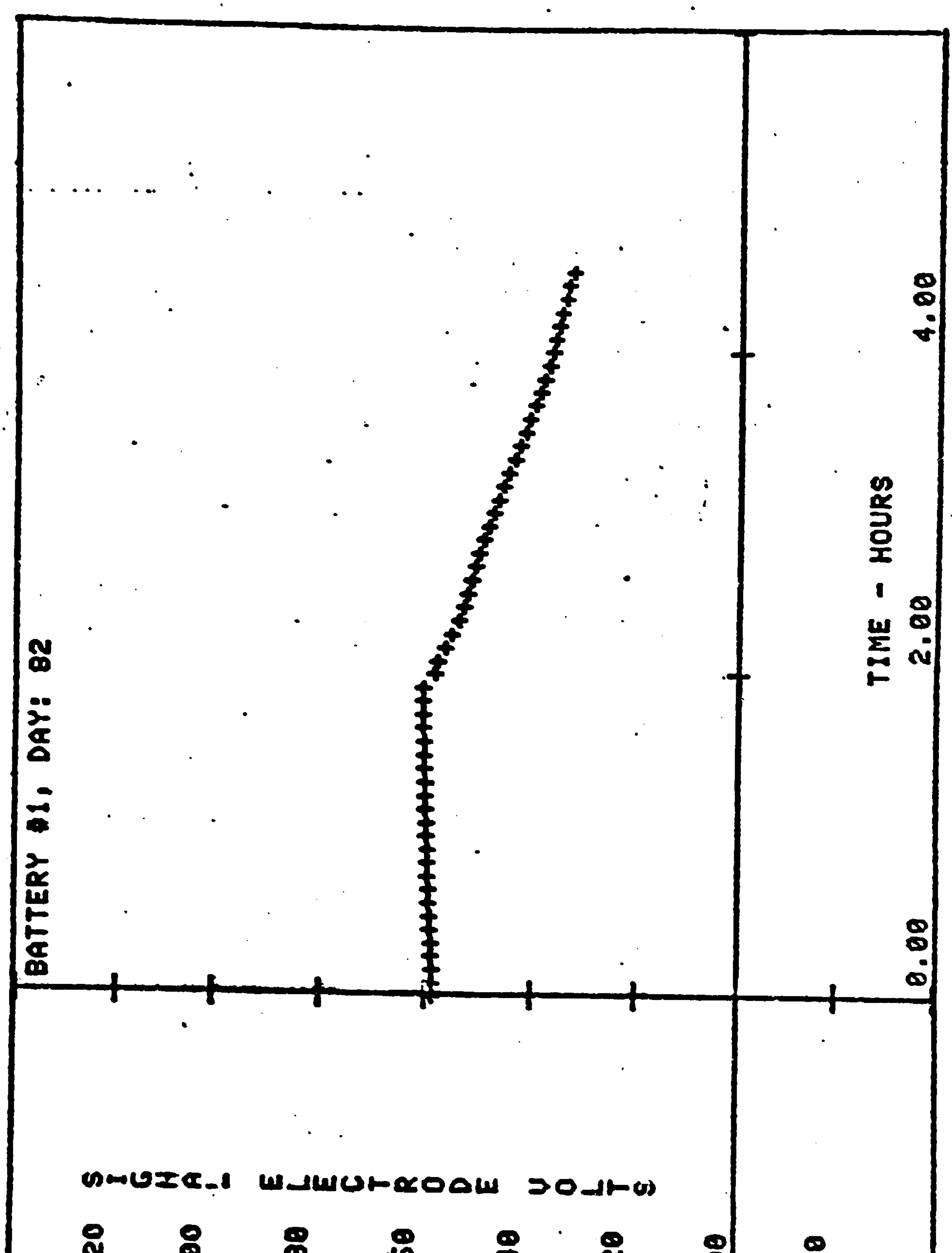
BATTERY #1, DAY: 01
E+1
3.00
2.00
1.00
0.00
-1.00
TEMPERATURE °C
Tc/10
0.00
2.00
4.00
TIME - HOURS

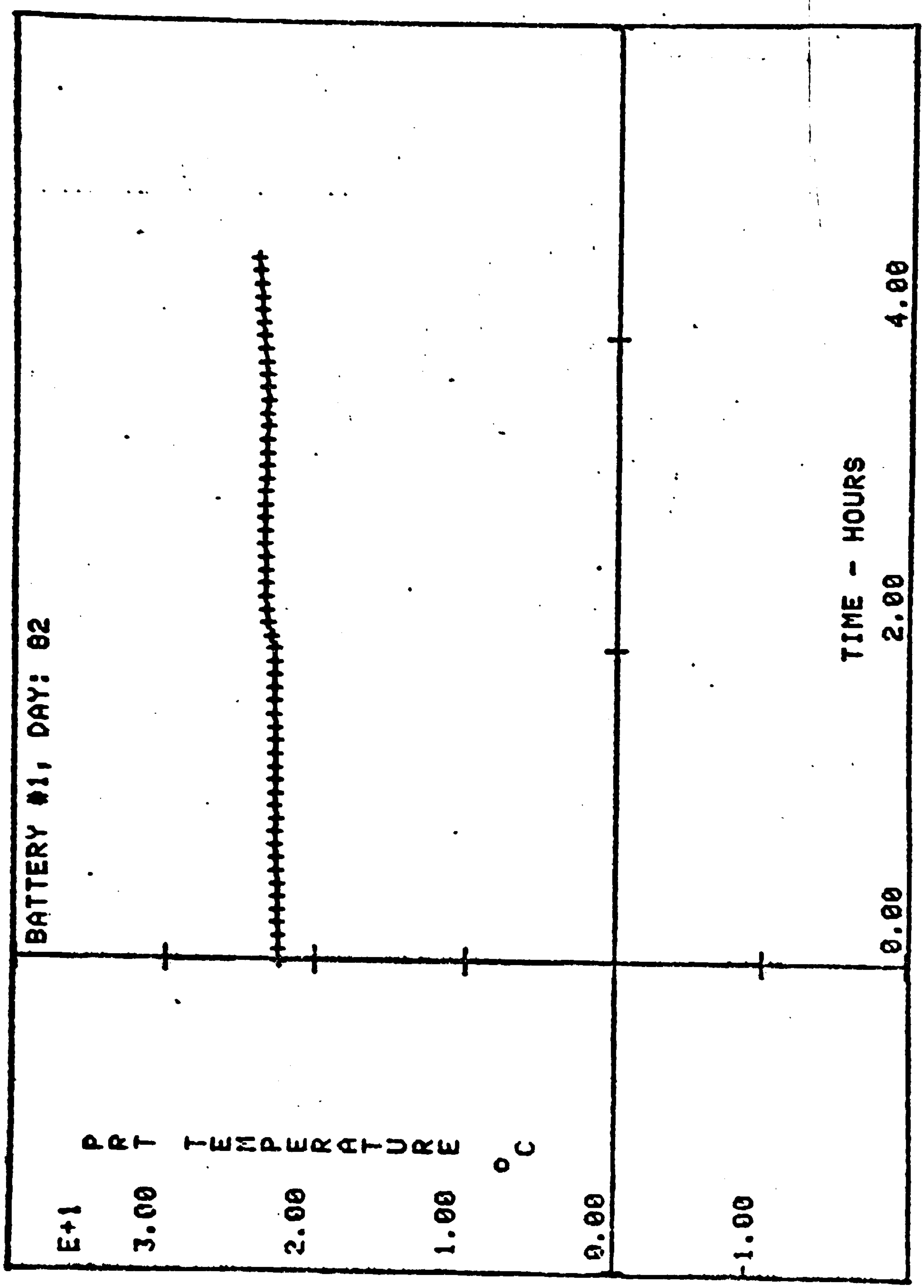

BATTERY 01, DAY: 61
TIME - HOURS
0.00
2.00
4.00
WATTS
E+2
1.00
0.00
-1.00
-2.00
-3.00
-4.00
-5.00

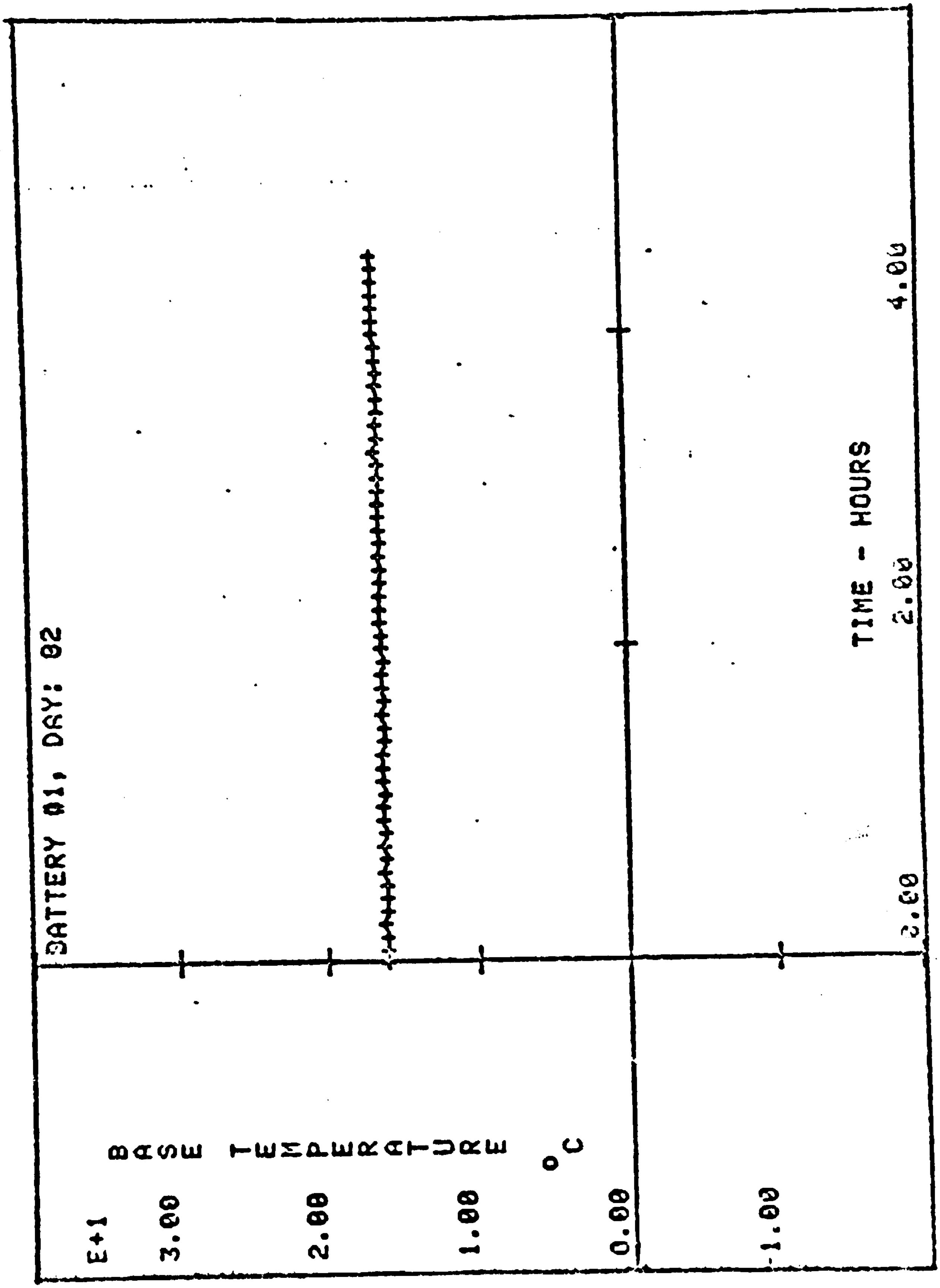

BATTERY #1, DAY: 02
TIME - HOURS
0.00
2.00
4.00
BATTERY VOLTAGE - VOLTS
E+1
3.00
2.50
2.00
1.50
1.00
0.50
0.00
-0.50

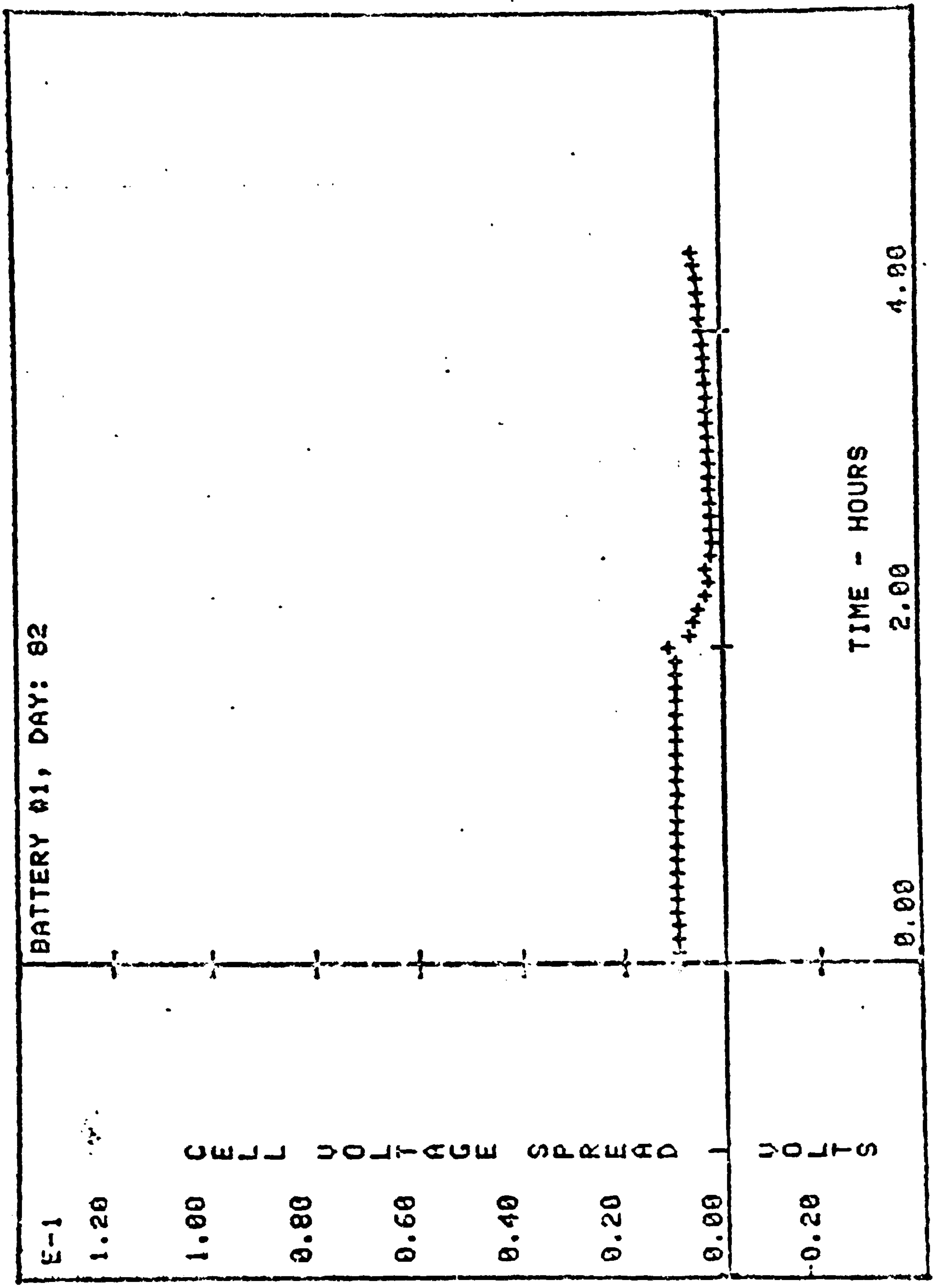

BATTERY #1, DAY: 82
TIME - HOURS
0.00
2.00
4.00
BATTERY CURRENT - AMPS
E+1
2.00
0.00
-2.00
-4.00
-6.00

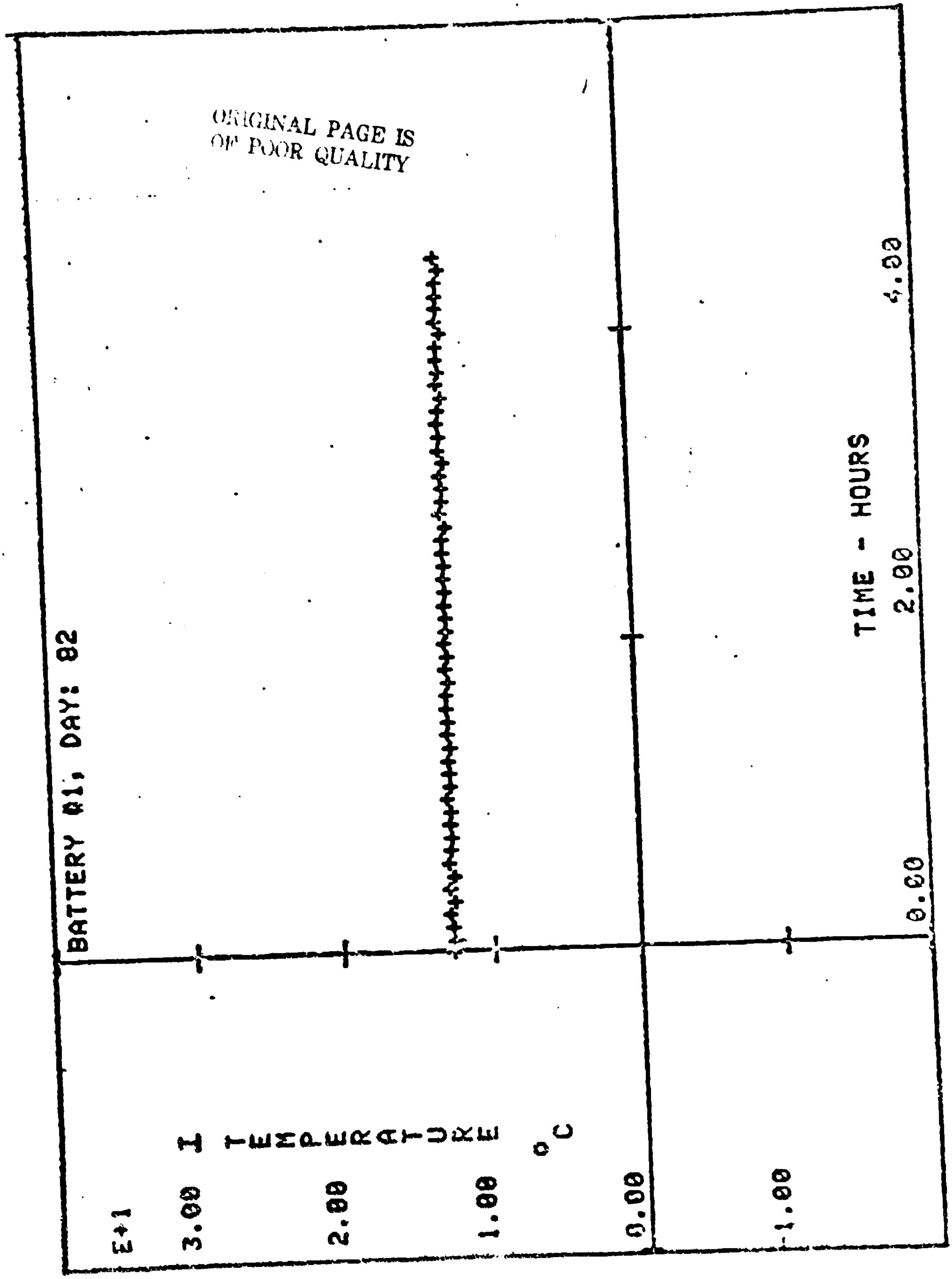


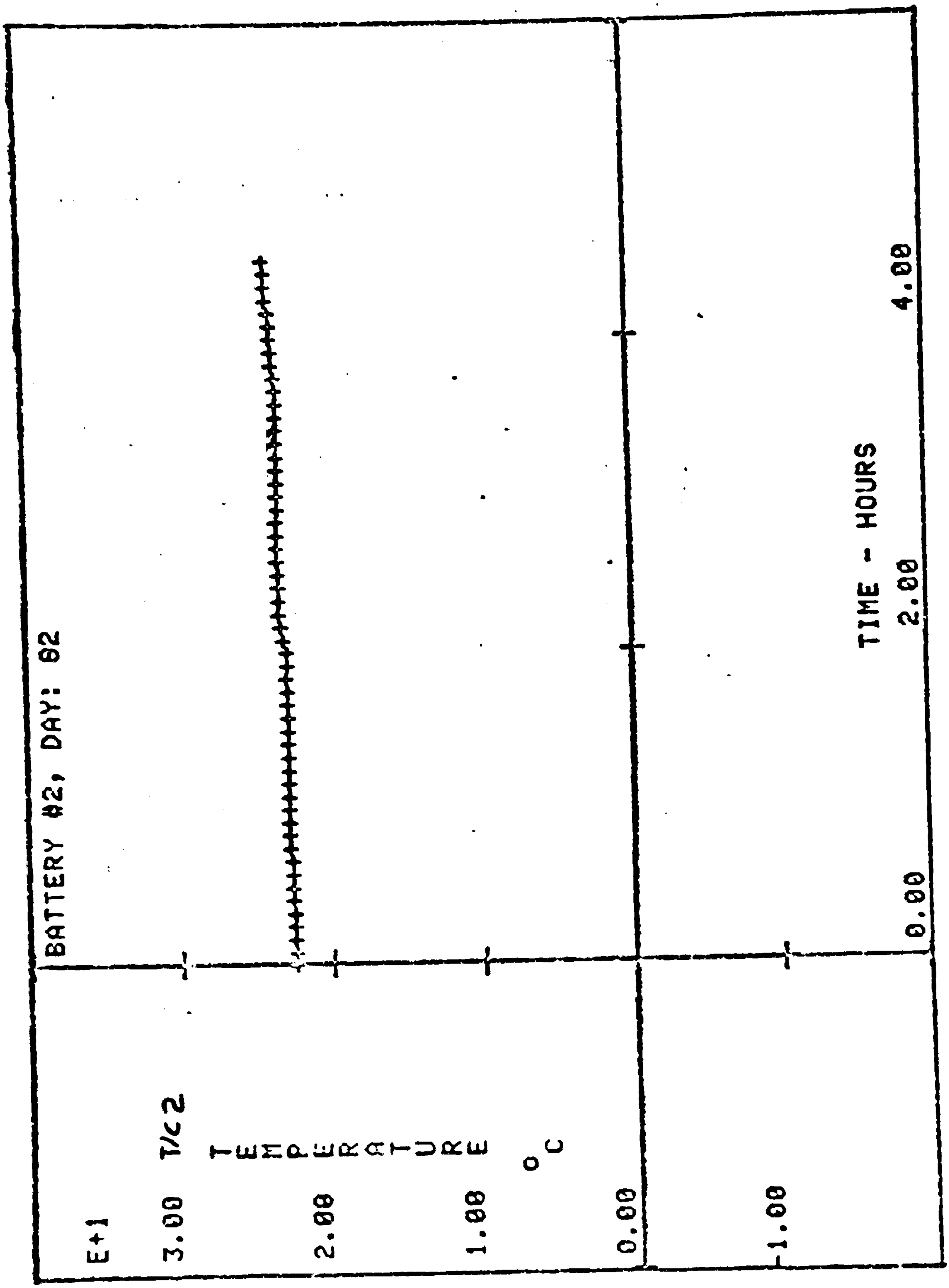
BATTERY #1, DAY: 82
SIGNAL ELECTRODE VOLTS
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
0.00
2.00
4.00
TIME - HOURS

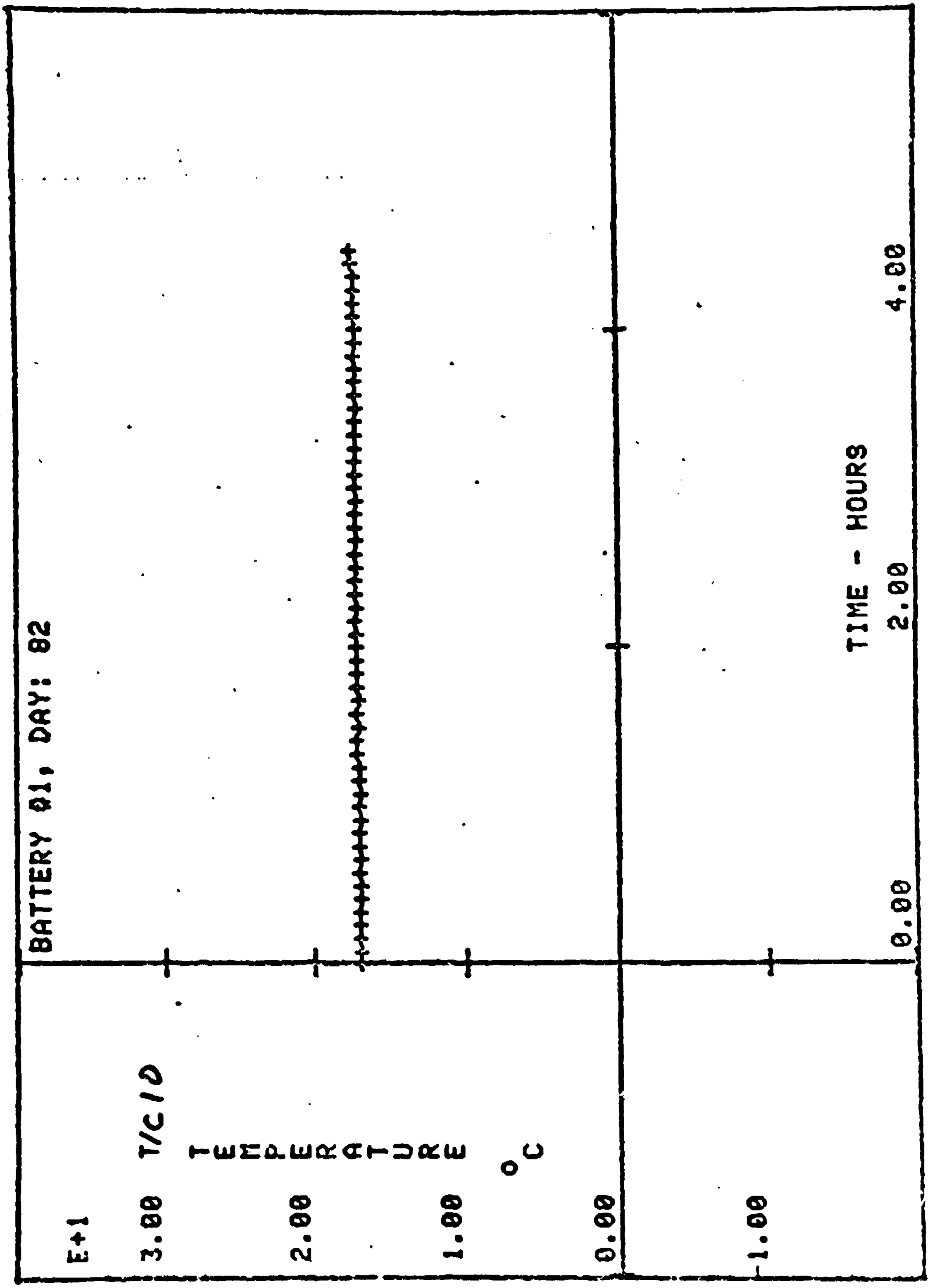

BATTERY #1, DAY: 82
TIME - HOURS
0.00
2.00
4.00
PRT TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00

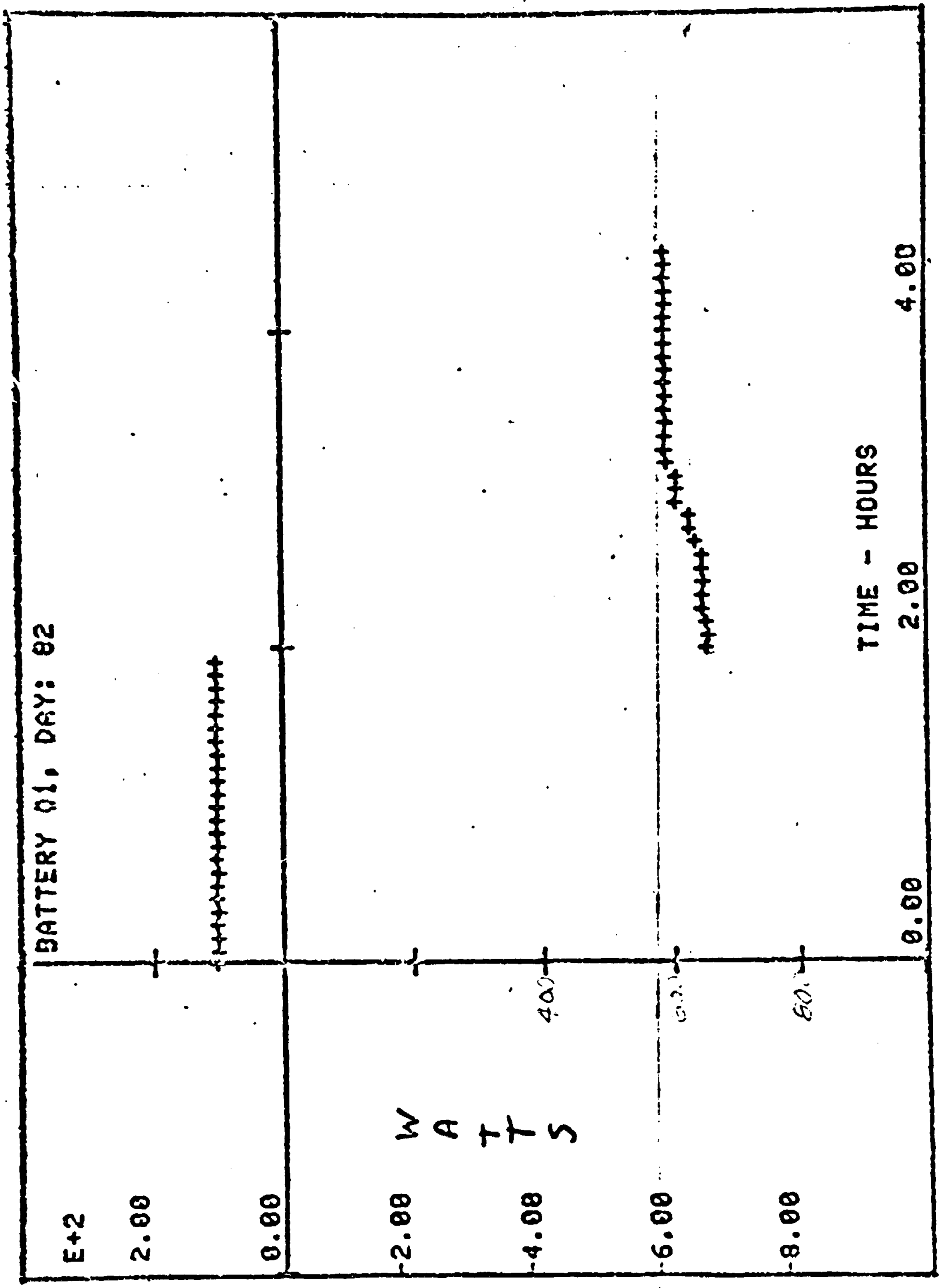

BATTERY 01, DAY: 02
BASE TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00
TIME - HOURS
0.00
2.00
4.00


BATTERY 01, DAY: 82
CELL VOLTAGE SPREAD - VOLTS
E-1
1.20
1.00
0.80
0.60
0.40
0.20
0.00
-0.20
TIME - HOURS
0.00
2.00
4.00


BATTERY 01, DAY: 82
TIME - HOURS
0.00
2.00
4.00
TEMPERATURE °C
E+1
3.00
2.00
1.00
0.00
-1.00


BATTERY #2, DAY: 02
E+1
3.00
2.00
1.00
0.00
-1.00
T/C 2
TEMPERATURE
°C
0.00
2.00
4.00
TIME - HOURS


BATTERY 01, DAY: 82
TIME - HOURS
0.00
2.00
4.00
E+1
3.00
2.00
1.00
0.00
-1.00
T/C 10
TEMPERATURE
°C



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APPENDIX B

50 A.H. Nickel-Cadmium

Spacecraft Battery

F

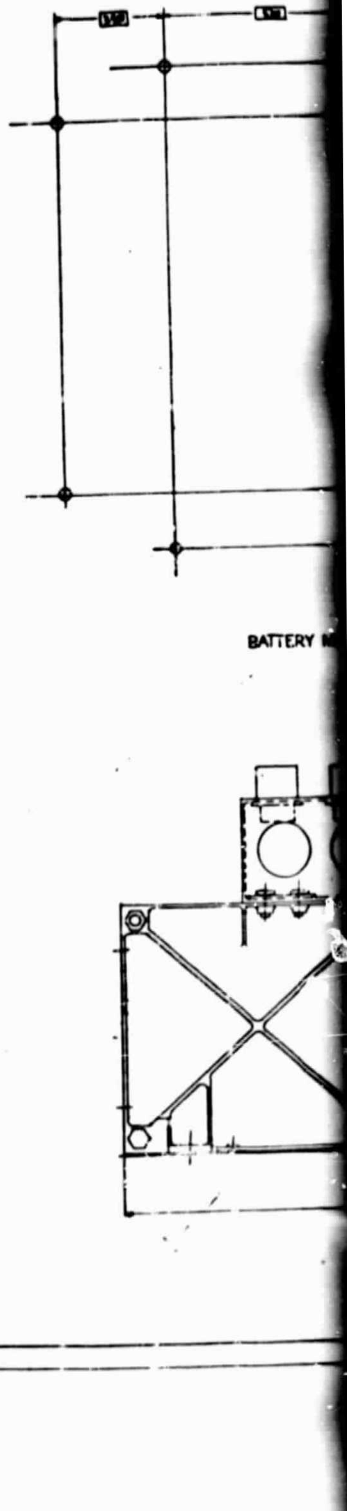
E

D

C

B

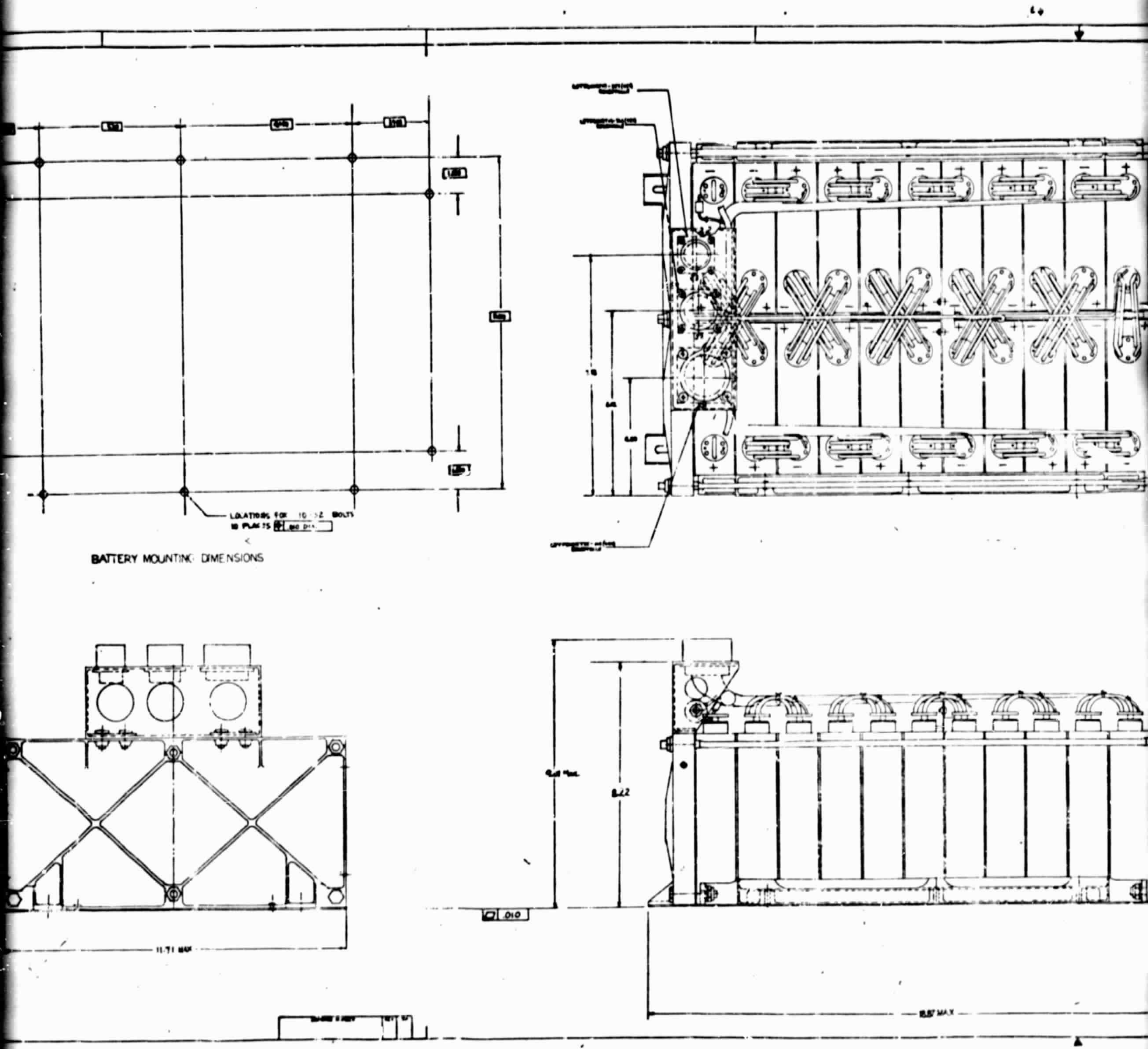
A



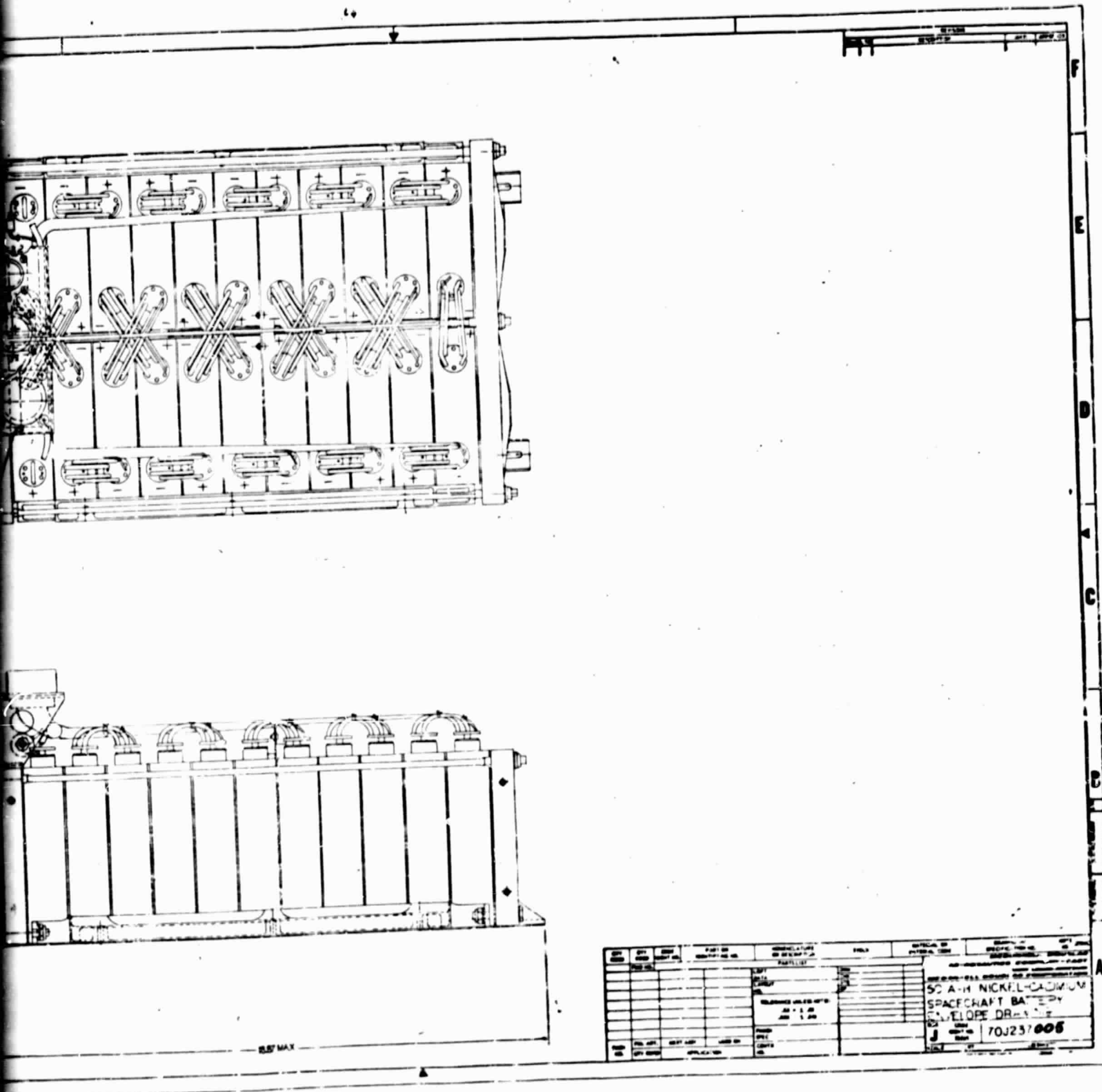
SPECIFICATIONS

NOMINAL CAPACITY	50 AH @ [illegible] RATE	TEMPERATURE SENSING	(1) PRECISION PLATINUM RESISTOR
NUMBER OF CELLS	22		(6) THERMISTORS
OUTLINE DIMENSIONS	19.84 in		(1) THERMOSTATIC SWITCH
	11.68 in	STATE-OF-CHARGE SENSING	(1) SIGNAL ELECTRODE CELL/BATTERY
	8.98 in		
NOMINAL WEIGHT	[illegible] lbs	THERMAL CONTROL	PASSIVE
MANUFACTURER	McDONNELL DOUGLAS ASTRONAUTICS CO. EAST	OPERATING TEMPERATURE	[illegible]°C TO 30° NOMINAL
PEAK DISCHARGE RATE	150 A FOR 5 MIN	NOMINAL DISCHARGE VOLTAGE	[illegible]
SUSTAINED DISCHARGE RATE	51 A	NOMINAL CHARGE VOLTAGE	31.24 V @ [illegible] RATE
		TERMINALS	ISOLATED FROM CASE

FOLDOUT FRAME



FOLDOUT FRAME 2



FOLDOUT FRAME 3